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The Research Landscape of Environmental Education for Sustainable Development in Basic Education: A Bibliometric Analysis

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ABSTRACT

Environmental education focused on sustainable development is essential for creating a sustainable future, since it provides individuals with the knowledge, skills, and attitudes necessary to address complex environmental issues. Such capabilities should be emphasized from the beginning of basic education. Therefore, it is essential to systematically explore research on environmental education for sustainable development in basic education. Using bibliometric methods, this study analyzed 391 scholarly articles retrieved from the core collection of Web of Science databases with the aid of VOSviewer. Identified key topic areas, influential publications, and emerging trends in the field through co-word and co-citation analysis. The co-word analysis revealed five primary clusters, whereas the co-citation analysis uncovered six principal clusters. The findings indicate a burgeoning academic interest in environmental education for sustainable development. The quantity of studies has consistently risen, and the subjects addressed have progressively broadened from fundamental environmental awareness to the development of transdisciplinary skills and the establishment of systematic thinking. Nonetheless, additional comprehensive research is required to thoroughly elucidate this field of study. This study has demonstrated useful insights for educators, policymakers, and academics to enhance the effective and comprehensive integration of sustainable development ideas into basic education.

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1. INTRODUCTION

Rapid industrialization has led to acute environmental issues. For example, intensifying contaminates and shortage of resources [1,2]. Environmental issues currently constitute a significant threat to human well-being [3,4]. According to a World Bank report, the globe produces over 1.3 billion tons of waste annually, a figure projected to rise to 2.2 billion tons by 2025 [5]. Against the backdrop of the growing global environmental crisis, overconsumption, resource wastage and environmental pollution have become urgent problems for human society. However, the Sustainable Development Goals (SDGs) still lack a clear

implementation path to address key topics such as environmental sustainability and social inequality [6,7]. In the face of this critical situation, environmental education (EE) is gradually being promoted as a sustainable tool for protecting the environment. Its core mission is for countries to push sustainable development through education and to foster the next generation with a sense of global citizenship and environmental responsibility [8].

Research has found that EE has undergone development and evolution, culminating in a more holistic education for sustainable development (ESD) [9]. It is evident that the introduction of SDGs into educational curricula is not just about adding content, but rather an educational paradigm shift that educates students not only to achieve academic success, but also to develop global citizenship, environmental stewardship, and social responsibility [10,11].There are many similarities between EE and ESD in terms of their approaches to practice, such as interdisciplinarity, lifelong learning, and prioritization of local and international problems when addressing consideration of local cultures. In addition, both are committed to changing people's perspectives and behaviors [12].ESD emphasizes a transformative and holistic approach to education, focusing not only on learning content and outcomes, but also on interactivity and practice orientation in order to develop global perspectives and responsible citizenship [13].ESD is thought to promote critical thinking and improve the skills required for effective decision-making, thereby aiding the development of sustainable societies [14]. And ESD should be started and gradually developed at the school level [15].

Environmental education for sustainable development (EESD) focuses on integrating the concept of sustainable development into all aspects of environmental learning [16]. EESD, as a crucial component of ESD, seeks to enhance environmental awareness, cultivate pertinent knowledge, and encourage responsible environmental conduct for sustainable development [17]. The core principles of EESD include continuity, inclusiveness, interdisciplinarity, integration, and unity [18], which inherits and expands the knowledge transfer function of traditional environmental education and emphasizes the combination of critical thinking and behavioral transformation, can be put into effect in different educational backgrounds from early childhood to higher education [19-21]. EESD is not only an important platform to cultivate students' awareness, understanding and participation in environmental issues, but also a key to promote individuals' active participation in sustainable development [12]. Meanwhile, in practice, teachers' readiness for EESD needs to evolve over time. For example, in countries such as India, educators are progressively incorporating environmental, social, and economic themes into the curriculum to augment students' awareness of sustainable development. In order to effectively implement EESD, it is important to develop a coherent national strategy, create a dedicated budget, reform relevant laws, and establish EESD-focused units within educational institutions [17].

On the other hand, in the school education system, the development of values has become one of the core tasks of teaching and learning [22]. The basic education stage is regarded as a key period for students' value shaping and competence development, usually covering pre-school, primary and secondary education. Based on this, the implementation of EESD in the curricula of various subjects, is the key to effectively responding to future environmental challenges.

Investing in children's environmental education is essential for both their future and the planet's future [23]. Despite the widespread acknowledgment of the significance of EESD, research on the effective implementation of EESD in basic education classrooms or activities remains insufficient. Specifically, there is a notable deficiency in comprehensive investigations regarding the strategies and methods teachers should employ to surmount pedagogical obstacles [24]. This fragmented status quo may make it

difficult for policymakers to identify priority areas. Therefore, for this lack of systematic analysis of the global research landscape, revealing the research hot-spots and knowledge evolution paths of EESD in basic education through bibliometric methods has become the key to cracking this dilemma. It holds substantial theoretical and practical importance.

Based on the above research questions, in order to systematically analyze the current research status of EESD in basic education and explore the possibilities of innovation in its teaching practice, this study, based on the relevant literature data from the WOS Core Collection as of February 24, 2025, utilizes VOSviewer to systematically analyze basic education and EESD's current state of research, revealing its association with innovations in teaching practice, and assessing scholarly contributions, identifying core themes and emerging trends to map its trajectory, and exploring its implications for basic education reform in conjunction with qualitative content analysis. This study underscores the necessity of staying informed about literature trends to address knowledge gaps, illustrate the field's evolution, and furnish critical insights and a scientific foundation for researchers, policymakers, and practitioners to enhance the integration and application of sustainable development within the basic education system.

The primary objective of this study is to identify the principal themes, research focal points, and prospective directions of environmental education within basic education, framed by sustainable development, through bibliometric analysis employing co-word analysis and co-citation network construction. The research was directed by two distinct objectives:

(1) Utilize co-word analysis to elucidate the fundamental topics, research focal points, and prospective trends in environmental education and basic education within the context of sustainable development.

(2) To identify the key theoretical frameworks supporting the practice of EESD and its interdisciplinary integration trends through co-citation analysis.

2. LITERATURE REVIEW

The United Nations discover the significance of environmental education in attaining sustainable development and highlights its role in the 2030 Agenda. Goal 4 of the Sustainable Development Goals emphasis the provision of inclusive, equitable, and premium education, while advocating for perpetual education for all humans. Target 4.7 under this objective emphasis the significance of integrating education for sustainable development into both formal and informal learning, encompassing environmental education [12].

William B. Stapp, the principal author of the founding document on EE, foreshadowed the triple focus of ESD in relation to the environment, social justice, and economic health [25]. Chapter 36 of Agenda 21 links environmental education to society, economy, and culture, underscoring its significance in attaining sustainable development [26]. The transition from EE to ESD was finalized by the Thessaloniki Conference declaration in 1997, wherein the term “environmental education” was entirely supplanted by “education for sustainability” or “education for sustainable development” [9].

EE emerged in its infancy in the 1980s. Early EE efforts focused mainly on nature-related experiences and the promotion of environmental preservation values. EE now takes a broader, cross-disciplinary approach and acknowledging the links among ecological, social and economic aspects in recent years. The transition from EE to ESD arises from the increasing acknowledgement of the interconnection between human welfare and planetary health, a change that has established ESD as an educational trend [12,27]. EE and ESD demonstrate a concurrent and interrelated existence within contemporary educational frameworks. Regardless of terminology, it is imperative to deliver premium education that facilitates an understanding of many perspectives [25].

Education is essential for cultivating awareness of the natural environment and advancing sustainable living. By imparting the significance of environmental protection, educators can motivate behavioral transformations that will contribute to the preservation of the Earth for future generations. EE fosters a sense of duty and stewardship towards the natural environment [22]. Therefore, there is a need to pay more attention to the development of environmental education through different programs that incorporate environmental education for sustainable development into educational curricula or promote sustainable development through international cooperation [16].

In developed countries, long-term EE has been recognized as an effective method for raising children's environmental awareness. These initiatives encompass Early Childhood Care and Education (ECCE) in New Brunswick, Canada, sustainable schools in Gothenburg, Sweden, and ecological learning activities in Nishinomiya, Japan [28-30]. In Colombia, EE has been the only pedagogical tool for schools and universities to achieve environmental sustainability, and it will guide the educational regulations for EE [31]. Meanwhile, the incorporation of local and indigenous knowledge systems into EE has been recognized for its cultural relevance and contribution to sustainability. Appreciating traditional ecological knowledge enhances the educational experience and deepens students' connection to local ecosystems [32].

From a policy and curriculum integration perspective. Over the past decade, six Southeast Asian nations - Brunei Darussalam, Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam - have created a toolkit for educators, course developers, and proponents of ESD. The toolkit integrates ESD into secondary education via the social studies curriculum, endorsed by the SEAMEO Innotech Regional Education Program (SIREP). It underscores the significance of social studies in relation to ESD and delineates the curriculum as a holistic framework for secondary-level instruction. Teachers, as user-developers, are expected to be curious and open-minded, driving curriculum transformation to better meet students' needs [33].

Effective integration of the SDGs into the curricula of different disciplines requires a variety of methods and strategies, including the design of professional development programs, regular assessment and feedback, and the selection of strategies for integrating scientific knowledge. Together, these methods and strategies form a comprehensive framework designed to improve the capacity of educational institutions to effectively integrate SDGs across disciplines [34]. However, with the ongoing reform of the National Curriculum, professional development training for teachers on ESD remains inadequate [35].

From the students' point of view, the learning environment as a subject of diminished significance, believing it lacks academic value [36]. Lower secondary schools in Greece are largely deprived of the concept of sustainable development, providing only sporadic and non-systematic knowledge about the concept. To promote EESD, a number of measures could be taken, such as adapting curricula to be more in line with the SDGs and providing resources to teachers from the central government to introduce sustainable development content in their teaching [27].

The study conducted by Winnie Wing Mui So et al. [24] examined the application of strategies and methodologies for incorporating Plastic Resources Education (PRE) into elementary education to address implementation challenges and foster environmental practices and sustainable development. In a study from Tanzania, for example, the researchers recommended that environmental protection be integrated into the Tanzanian general secondary school curriculum along with social development and economic growth. This is significant as economic progress frequently results from inequitable trade-offs, disregarding environmental repercussions and the communities reliant on the environment and its resources for sustenance [37].

Regarding the use of bibliometrics to analyze the relationship between EESD and other factors, Lasino et al. [12] applied bibliometric analysis based on the literature from 1961 to 2023 in several databases of Scopus, Web of Science, ERIC, and Google Scholar to conduct an analysis of the EESD field of Curriculum design and pedagogy research was reviewed. The study focuses specifically on curriculum design and pedagogy, emphasizing the keywords "curriculum design", "environmental education" and "sustainable development". In addition, research topics include climate change education, social justice, and sustainable consumption. Varsha Arya et al. [16] conducted a bibliometric analysis of research on EE and sustainable enterprising spirit development up to 2022, and proposed future directions such as integration of EE and sustainable entrepreneurship practices, multi-level policy development, and research focus on the impact of EE on different social groups. social groups impacts are the focus of the research. Although studies have been conducted focusing on the role of curriculum design, pedagogy and policy integration in EESD, most of them have concentrated on higher education or vocational education, while the specialized exploration of EESD aspects at the basic education level is still relatively limited.

This study seeks to establish a scientific foundation for forthcoming educational reforms, utilizing EESD as a catalyst to enhance the effective integration of environment sustainable development principles in basic education, and to foster a greater number of future citizens endowed with environmental responsibility and innovative thinking.

Therefore, this study proposes the following two hypotheses:

(1) Co-word analysis indicates that keywords such as sustainable development, environmental education, and basic education exhibit high-frequency co-occurrences in research pertaining to EESD and basic education, underscoring their growing significance in the field and highlighting the developmental trajectory of potential emerging research themes or sub-fields.

(2) The co-citation analysis reveals significant literature that exerts a crucial influence on the study of EESD and basic education, providing a theoretical foundation and fostering interdisciplinary integration in the field.

3. METHODS

This section delineates the particular use of bibliometric analytic method in this study.

3.1 Bibliometric approach

Bibliometric analysis as a methodology enables a comprehensive assessment of the current status of a particular research area by examining available publications, including authors, keywords, place of publication, source and country [38,39]. The main advantage of bibliometric analysis is the conversion of abstract scientific material into organized and understandable forms [40,41]. To facilitate bibliometric visualization and analysis and to identify bibliometric clusters, the study uses the widely used bibliometric software VOSviewer.

Co-word analyses and co-citation analyses deepened structural assessments and future direction maps [42]. Co-word analysis explores interactions between keywords, thus pointing out influential themes [43]. Co-word analysis evaluated trend evolution and conceptual linkages by extracting data from titles, keywords, or abstracts [44,45]. Co-citation analysis relies on counting simultaneous citations and use co-citation metrics to evaluate commonalities among documents, periodicals, and authors [39].

3.2 Research design and data collection process

First, literature information needs to be retrieved and collected from Web of Science (WOS) databases. Chose the WOS database for bibliometric analysis because the WOS database has high quality and comprehensive content [46]. Recent

literature indicates that a singular database, such as WOS, acknowledged as a highly dependable source, is frequently utilize in bibliometric analyses. The methodology was devised to address the necessity of manually consolidating data in various formats, which poses a danger of human mistake [47]. The search terms have been carefully selected to cover all aspects of environmental education for sustainable development and basic education. The search contained keywords ("sustainable development*" or "environmental education*" or "ecological education*" or "environmental responsibility*" AND "basic education*" or "secondary education*") as the main focus of the study. The asterisk (*) facilitates the incorporation of diverse terminology and phrases associated with these principal themes [48]. Table 1 delineates the precise information utilised for the literature search and screening.

It is worth noting that, in conjunction with the above, it is clear to recognize that EESD is an expanded form of EE within the framework of sustainable development, but not all EE researchers use the term EESD directly. Many studies may address the inclusion of sustainability in EE but do not directly use the EESD terminology, and a broad search strategy could encompass a wider range of potentially relevant literature. Therefore, a separate search for "sustainable development" and "environmental education" would cover all EE studies involving a sustainable development perspective to ensure that more relevant studies are covered. A search of the WOS core collection yielded 501 publications, including article, conference proceedings, review papers, online publications, editorial materials, and conference abstracts. Bibliometric analysis for this study was conducted on article only, so literature other than article was filtered out, yielding 391 articles.

Secondly, a quantitative bibliometric analysis was carried out to elucidate the study on EESD and basic education. In this phase, two main components were included: (1) The analysis of annual publication trends; (2) The scientific mapping process, which used the bibliometric software VOSviewer, version 1.6.20.

This study analyzes based on keyword co-occurrence and co-citation with the aim of examining research collaboration networks and elucidating the latest academic trends. It involves clustering decentralized knowledge in different domains based on similarity and relevance. In visual networks, nodes signify distinct entities, including references and keywords. Nodes with high similarity are grouped and color-coded to form distinct clusters, whereas those with lower similarity are positioned farther apart to emphasize separation [49].

Thirdly, this study used qualitative thematic analysis to interpret the mapping produced by VOSviewer and further elaborated its findings through narrative language and tables.

Table 1. Search string

WOS Database	**Web of Science Core Collection**
Time period	Up to February 24, 2025
Search field	Topic
Search keywords	"sustainable development*"or "environmental education*"or "ecological education*"or "environmental responsibility*"AND "basic education*"or "secondary education*"
Document Type	Article
Citation topics	All
Languages	All

4. RESULTS AND DISCUSSION

The findings from VOSviewer's bibliometric analysis offer significant insights into the present condition of EESD research within basic education. This section includes a statistical examination of publication trends, co-word analysis, and co-citation analysis.

4.1 Publication trends and descriptive analysis

Figure 1 shows the publication and citation of articles from 1997 to February 24, 2025. As seen through the publication trends, although research on this topic first began in 1997, significant progress was not made until 2018. Subsequently, the number of relevant publications has grown dramatically. In the early stages (1997 to 2015), the number of relevant publications was low and the average annual growth was weak, indicating that the topic received less attention in academia. At the same time, the number of citations also remained at a low level, indicating that a more mature research system has not yet been formed in the field. The turning point was in 2018, after which the number of publications ushered in a rapid rise. the annual publication volume reached about 50 to 70 between 2020 and 2024, reflecting the gradual increase in the influence of this research direction in academia. Meanwhile, the number of citations shows a similar trend, climbing significantly after 2019 and exceeding 650 in 2024, indicating that the research results in this field have been widely noticed and cited during this period. Overall, research in this field enters a rapid development phase only after 2019, indicating that the field is relatively new. This trend may be influenced by factors such as policy promotion, growth in social demand, or increased academic attention to the issue. The cumulative effect of the research results also facilitated the expansion of subsequent studies to a certain extent, resulting in a rapid increase in citations within a short period of time and reaching a peak in 2024. This evolving tendency not only underscores the significance of EESD in foundational education within the academic sphere but also furnishes a robust theoretical framework and empirical support for forthcoming study.

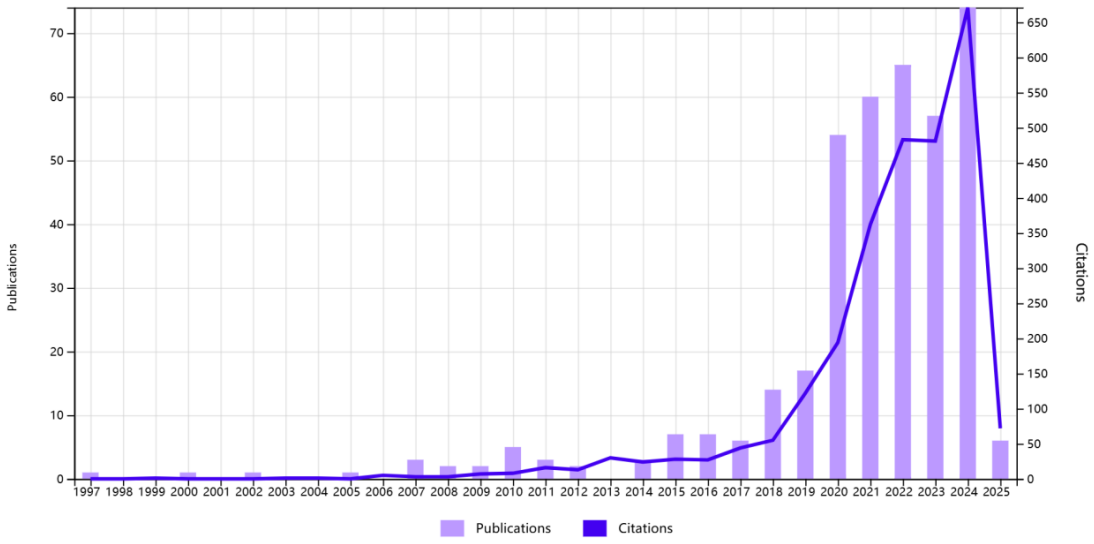

Figure 1. Number of publications and citations, 1997 to February 24, 2025 (Source: Web of Science).

4.2 Co-occurrence of keyword

Co-word analysis in VOSviewer was selected as "co-occurrence: All keywords". 42 keywords were identified for co-word analysis by replacing synonyms and setting a minimum of 6 occurrences for each identified keyword. The VOSviewer analysis results offer significant insights into the present condition of research on EESD in basic education. The co-word analysis revealed that the most prevalent keyword was "environmental education," appearing 90 times. While "basic education" and "sustainable development" was placed second and third, with 84 and 54 instances, respectively. The top 10 co-occurring keywords were extracted as shown in Table 2. Figure 2 illustrates the visual network diagram derived from the co-word analysis. Figure 3 shows the cluster classification of the co-word analysis, which consists of five interrelated clusters. Each cluster emphasizes the main keywords prevalent in the selected literature, and the characteristics of each cluster are analyzed and discussed:

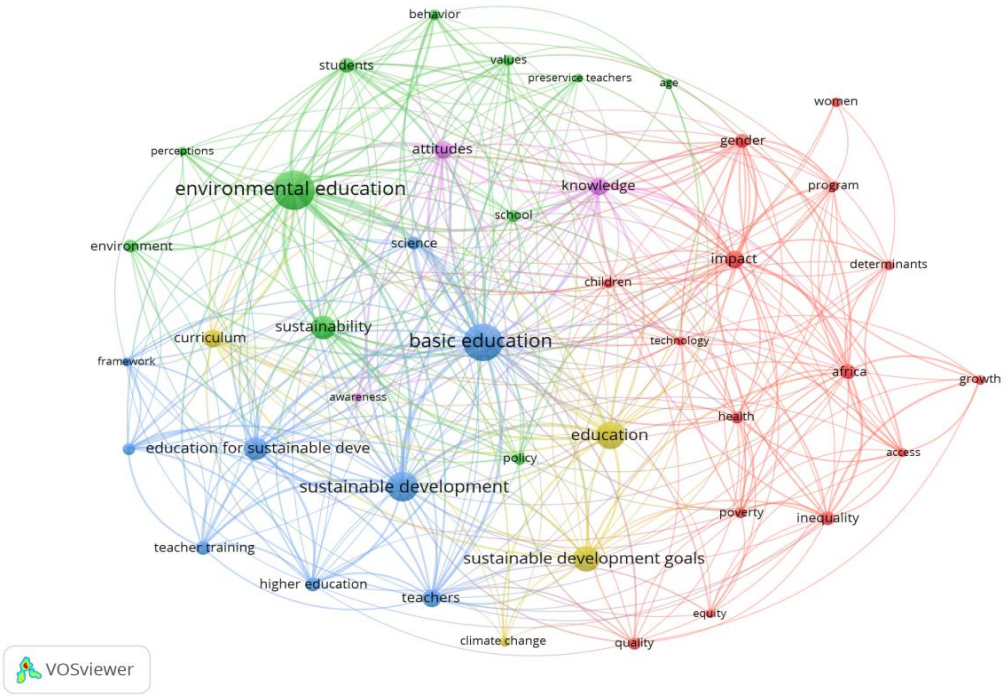

Figure 2. Co-word analysis (Source: VOSviewer visualization).

Table 2. Keyword co-occurrence analysis top 10 keywords

Rank	Keyword	Occurrences	Total link strength
1	Basic education	84	181
2	Environmental education	90	151
3	Sustainable development	54	97
4	Education	48	83
5	Knowledge	21	79
6	Sustainability	35	74
7	Education for sustainable development	34	73
8	Attitudes	22	71
9	Impact	21	64
10	Teachers	21	56

Source: VOSviewer Co-occurrence : All keywords analysis

Cluster 1 (Red) consists of 15 keywords and primarily focuses on the impact of socially equitable and technology-driven ESD. This cluster is centered around the keyword “impact,” highlighting the multidimensional social effects of ESD in basic education. Keywords such as “Africa” “children” “gender” “poverty” and “inequality” indicate a strong emphasis on educational equity issues concerning marginalized regions (e.g., Africa) and vulnerable groups (e.g., children and women), underscoring the role of technology and health interventions in breaking the cycle of poverty and reducing gender disparities. For instance, terms like “equity” and “access” reflect challenges related to unequal resource distribution, while “program” and “quality” point to the design and evaluation of educational initiatives. Furthermore, this cluster explores how ESD can drive structural reforms, including policy support and technological empowerment, to foster socioeconomic growth and inclusive development. Given that the implementation pathways for achieving the SDGs in addressing environmental sustainability and social inequality remain insufficiently defined [6,7], the findings of this cluster offer empirical insights for policymakers. These insights contribute to optimizing resource allocation in basic education, ensuring that technology-driven educational innovations benefit marginalized populations. This, in turn, advances progress toward global sustainability objectives, particularly in response to SDG 4 (Quality Education) and SDG 5 (Gender Equality).

Cluster 2 (Green) consists of 15 keywords. It focuses on environmental behaviors and the shaping of pr-service teachers' values. The cluster focuses on “environmental education,” emphasizing its practical application within basic education. The key words “behavior”, “perceptions” and “values” indicate that the study focuses on the formation mechanism of students' environmental behavior, especially the internalization process of values. The training content of preservice teachers, as key actors, may influence the implementation of ESD in schools. The study also underlines the significance of the “school” as a field of practice for developing students' sense of environmental and ecological responsibility through curriculum design and outdoor activities such as “environment”. The combination of “students” and “age” reveals differentiated strategies for behavioral education at different school ages. The findings of this cluster call for the strengthening of teacher professional development systems, the integration of environmental ethics into teacher education, and the promotion of the transition from knowledge to action through school-based practices.

Cluster 3 (Blue) comprises nine keywords and principally emphasizes capacity building for sustainable growth within the fundamental education system. This cluster is centered around the keyword “basic education,” emphasizing the systematic integration of ESD into foundational education. Keywords such as “competences,” “framework,” and “teacher training” indicate that research in this cluster aims to establish interdisciplinary competency frameworks and enhance teaching practices through science education and teacher professional development. The connection between “education for sustainable development” and “higher education” reflects the need for alignment between basic and higher education in attaining sustainability goals. Moreover, the research highlights that “teacher training” should incorporate localized case studies to assist educators in translating abstract concepts, such as the SDGs, into actionable curriculum content. Findings suggest that training teachers and

providing professional development programs enable educators to realign curricula to better support the United Nations 2030 Agenda for Sustainable Development [50]. The outcomes of this cluster offer educational administrators' capacity-building models that advocate for a teacher-centered, curriculum-based systemic reform, ensuring the deep integration of ESD into basic education.

Cluster 4 (Yellow) consists of 4 keywords. It focuses on curriculum integration and localized responses to global issues. This cluster is centered on "education", focusing on the deep integration of the SDGs and curriculum. The keyword "climate change" highlights the direct impact of the global environmental crisis on the content of basic education, and the study emphasizes the development of climate literacy through interdisciplinary curriculum design, such as the integration of science and social sciences, with the aim of promoting sustainable development through environmental education. Through the strong association between "curriculum" and "education", we can see that the curriculum is not only a tool for knowledge transfer, but also a medium for shaping values. The results of this cluster call on educators to break down disciplinary barriers and develop problem-oriented modules, such as project-based learning to explore solutions to climate change, in order to empower students to think and act critically on the global issue of the environment.

Cluster 5 (Purple) consists of 3 keywords. It focuses on the enlightenment path of sustainable development awareness and cognition. The cluster focuses on the cognitive enlightenment mechanism in ESD with "attitudes" as the core. The keywords "awareness" and "knowledge" reveal the progressive relationship from knowledge accumulation to attitude change, and the study emphasizes that the basic education stage is a golden window for shaping ecological values. The correlation between "attitudes" and "awareness" indicates that traditional teacher-centered methods may hinder creative thinking and lower student engagement. Adopting interactive, non-traditional strategies is recommended to enhance learning interest [51]. Therefore, simple knowledge inculcation is not enough to promote behavioral change, which needs to be done through emotional resonance. For example, ecological narratives are taught to stimulate intrinsic motivation in students. The findings of this cluster provide educators with strategic recommendations for designing experiential learning activities, such as community environmental practices, to transform abstract concepts into embodied experiences, thus realizing the multidimensional penetration of EESD at the cognitive, affective, and action levels.

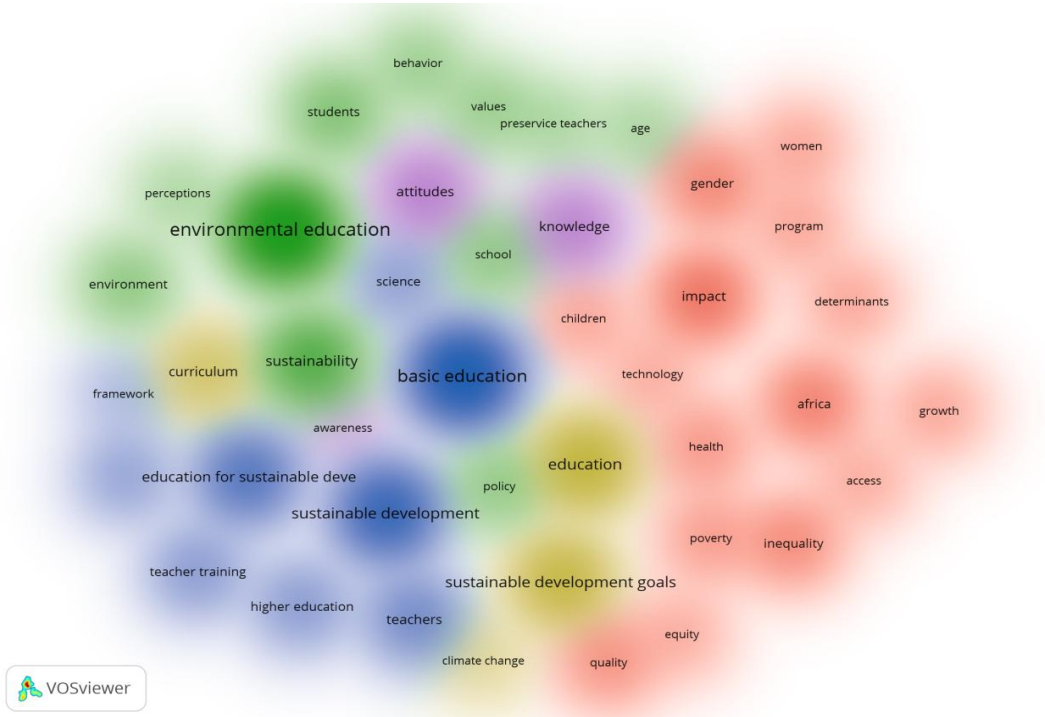

Figure 3. Cluster details (Source: VOSviewer visualization).

This study employs co-word analysis to reveal the research landscape of EESD in basic education, identifying five major clusters that provide valuable insights for policymakers and educational practitioners. These findings contribute to the development of more targeted educational strategies, facilitating the advancement of EESD in basic education on a global scale.

Table 3 encapsulates the co-word analysis of literature pertaining to EESD and basic education, detailing the quantity of keywords in each cluster, representative keywords, and all detected keywords. Consequently, Hypothesis 1 is confirmed.

Table 3. Co-word cluster results

Cluster	Number of keywords	Most frequent keywords (occurrences)	Keywords
1 (Red)	15	Impact (21)	Access, Africa, children, determinants, equity, gender, growth, health, impact, inequality, poverty, program, quality, technology, women
2 (Green)	11	Environmental education (90)	Age, behavior, environment, environmental education, perceptions, policy, preservice teachers, school, students, sustainability, values
3 (Blue)	9	Basic education (84)	Basic education, competences, education for sustainable development, framework, higher education, science, sustainable development, teacher training, teachers
4 (Yellow)	4	Education (48)	Climate change, curriculum, education, sustainable development goals
5 (Purple)	3	Attitudes (22)	Attitudes, awareness, knowledge

Source: VOSviewer Co-occurrence : All keywords analysis

4.3 Co-citation analysis

This study utilizes co-citation analysis of cited references. With a co-citation threshold of 5, a total of 46 cited references were initially identified. After screening, 41 references were ultimately selected. Figure 4 illustrates the VOSviewer visualization network analysis, while Table 4 enumerates the five most cited sources. The co-citation analysis delineates six distinct clusters, each characterized by a particular thematic focus. These clusters represent publications that share thematic relevance and intellectual connections. Nodes of the same color indicate clusters of publications with common research themes. The definition and detailed interpretation of each cluster are as follows:

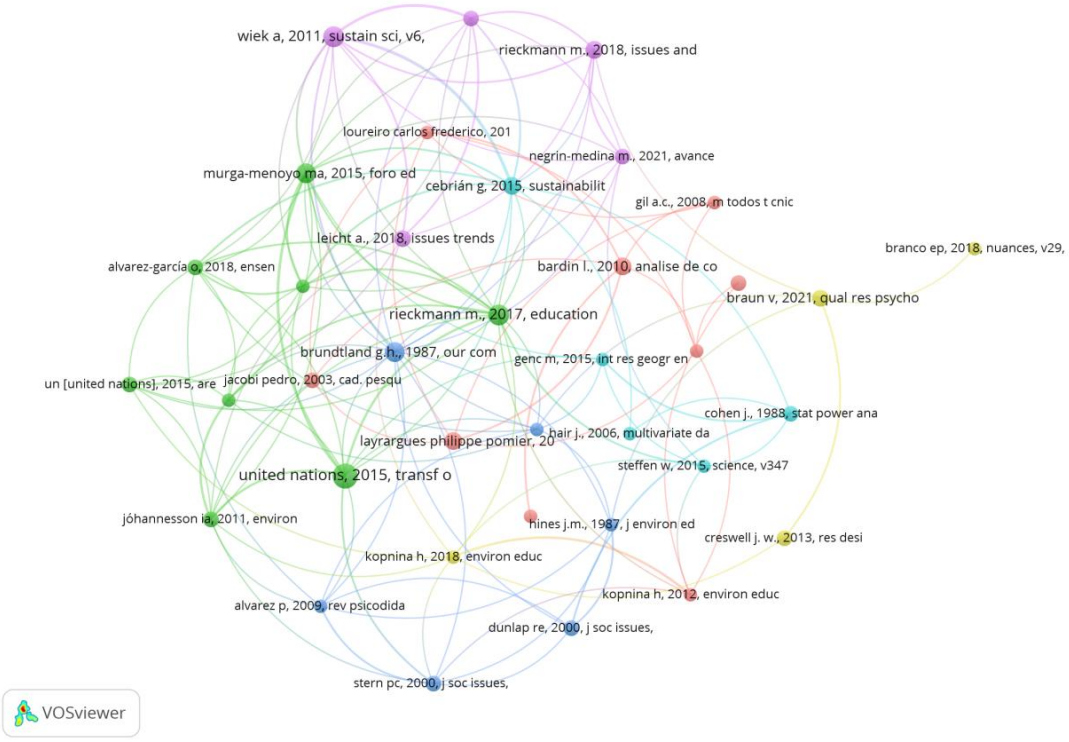

Figure 4. Co-citation analysis (VOSviewer visualization)

Table 4. Top 5 cited reference ranked by co-citation and total link strength

No.	Cited reference	Citation	Total link strength
1	Wiek, A., Withycombe, L., & Redman, C. L. (2011). Key competencies in sustainability: A reference framework for academic program development. *Sustainability Science, 6*, 203-218. [52]	10	29
2	Rieckmann, M. (2017). *Education for sustainable development goals: Learning objectives.* UNESCO. [53]	10	28
3	United Nations. (2017). Transforming our world: The 2030 agenda for sustainable development. [54]	14	25
4	Cebrián, G., & Junyent, M. (2015). Competencies in education for sustainable development: Exploring the student teachers' views. *Sustainability, 7*(3), 2768-2786. [55]	8	24
5	Murga-Menoyo, M. Á. (2015). Competencias para el desarrollo sostenible: Las capacidades, actitudes y valores meta de la educación en el marco de la Agenda global post-2015. *Foro de Educación, 13*(19), 55-83. [56]	9	24

Source: VOSviewer Co-citation : Cited references analysis

Cluster 1 (Red) consists of nine references. This cluster explores multiple perspectives on EE and ESD, examining how education contributes to achieving sustainability goals. The research primarily focuses on how curriculum design, educational interventions, and policy measures can enhance learners' awareness of environmental sustainability and drive behavioral change. Studies within this cluster discuss the evolution of EE concepts, the development of core competency frameworks, and the importance of interdisciplinary integration. For instance, Kopnina examines the transition from EE to ESD within the context of environmental ethics, advocating a return to instrumentalism and emphasizing that educating ecologically conscious students can help address complex environmental challenges [57]. Additionally, this cluster includes studies on the implementation of ESD at various educational levels, analyzing effective teaching methods and evaluation strategies. This cluster highlights the intersection between EE and ESD, illustrating that sustainability is not only a knowledge system but also a practice-oriented educational approach. It underscores the necessity of policy support, curriculum innovation, and collaboration among multiple stakeholders to achieve long-term educational objectives.

Cluster 2 (Green) consists of eight references and primarily focuses on teacher training and curriculum development in ESD. This cluster explores the role of teacher training and curriculum design in fostering sustainable education, analyzing teachers' sustainability competencies, including their understanding of the SDGs, adaptability to teaching methodologies, and ability to integrate sustainability concepts into classroom instruction. Murga-Menoyo [56] specifically examines the training required to develop the skills and competencies necessary for building a sustainable society. The findings of this cluster indicate that teachers play a crucial role in effectively implementing environmental education in the classroom, as systematic training directly influences students' sustainability awareness and practical engagement [59]. However, if educators lack the requisite information, attitudes, skills, or dedication to environmental conservation, they are less likely to cultivate environmental citizenship among their students. This cluster encompasses teacher training programs, professional development initiatives, and strategies for integrating sustainability objectives into curricula at various educational levels to ensure the long-term effectiveness of ESD. Furthermore, the research highlights the challenges teachers face in the classroom, such as time constraints, rigid curriculum standards, and limited resources, highlighting the need for policy support and interdisciplinary collaboration to enhance the quality of teacher training in sustainability education.

Cluster 3 (Dark Blue) consists of six references and primarily examines environmental attitudes, behaviors, and the underlying theoretical frameworks, exploring how individuals and groups cognitively, emotionally, and behaviorally respond to environmental issues. The research in this cluster focuses on the application of psychology, sociology, and behavioral sciences in environmental education, analyzing factors that influence individuals' engagement in sustainable actions, such as values, social norms, environmental awareness, and situational factors [63,64]. The theoretical models within this cluster include the Theory of Planned Behavior (TPB), the Value-Belief-Norm (VBN) Model, and Self-Efficacy, which help explain the decision-making processes of individuals and social groups regarding environmental

actions [64]. The VBN model particularly emphasizes the role of personal values, environmental beliefs, and the resulting sense of responsibility in shaping pro-environmental behavior, positioning environmental responsibility as a core driver of individual action. Additionally, Dunlap et al. [65] introduced the New Ecological Paradigm (NEP) scale, which has been widely used to assess individuals' environmental attitudes, highlighting how perceptions of human-nature interactions influence environmental behaviors. Furthermore, this cluster explores behavioral intervention strategies in environmental education, such as experiential learning and citizen science projects, including community-based management initiatives, to strengthen individuals' sense of environmental responsibility [64]. The findings of this cluster emphasize that environmental education is not merely about knowledge transmission but also about fostering a sense of responsibility, enabling individuals to transform environmental awareness into concrete sustainable actions.

Cluster 4 (Light Blue) consists of five references and primarily focuses on the core competencies and learning approaches in sustainability education, exploring how education can develop students' critical thinking, systems thinking, collaboration skills, and problem-solving abilities to address global sustainability challenges. This cluster examines various teaching models, including project-based learning [66], interdisciplinary teaching and learning approaches, and transformative social learning, assessing their effectiveness in ESD. The research also investigates the role of specific methods in sustainability learning, emphasizing how participatory learning approaches enhance the overall learning experience. For instance, Cebrián & Junyent [55] highlight the importance of active and participatory learning, which may be linked to blended learning approaches. Studies within this cluster emphasize that fostering sustainability-oriented thinking relies on promoting active learning, enabling students to apply their knowledge to real-world social and environmental challenges, ultimately developing long-term sustainable action capabilities.

Cluster 5 (Purple) consists of five references and focuses on the policy and institutional frameworks of ESD. This cluster examines how governments, schools, and educational institutions implement ESD through policy measures [67]. It explores the impact of educational policies on the promotion of ESD curricula and how international organizations contribute to policy adjustments to address global environmental challenges [52]. Additionally, this cluster discusses the evaluation of education policies, analyzing case studies of ESD policy implementation across different countries or regions, comparing the effectiveness of various policies, and extracting best practices. The findings contribute to the development of more adaptable and actionable policy frameworks, providing theoretical support and practical guidance for future ESD policy advancements.

Cluster 6 (Yellow) consists of four references and primarily focuses on environmental education policies and teaching methods. Compared to Cluster 5, this cluster places greater emphasis on specific pedagogical approaches, examining how teachers implement environmental education in the curriculum and translate SDGs into classroom practices. It explores how educators utilize situated learning and collaborative learning to enhance students' environmental awareness and engagement. Additionally, this cluster investigates the impact of policies on the selection of teaching methodologies and how different educational systems integrate environmental education

within policy frameworks [69]. The research in this cluster highlights the intersection of education policies and pedagogical strategies, providing theoretical support for the effective classroom implementation of EESD.

Table 5. Co-citation clusters details

Cluster	Label	Number of publications	Representative publications
1 (Red)	Environmental Education and Sustainable Development Perspectives	9	[57,58]
2 (Green)	Teacher Training and Curriculum in Education for Sustainable Development	8	[53] [56] [59-62]
3 (Dark Blue)	Environmental Attitudes, Behavior, and Theories	6	[63-65]
4 (Light blue)	Competencies and Learning Approaches in Sustainability Education	5	[55] [66]
5 (Purple)	Policy and Institutional Frameworks for Sustainable Education	5	[52] [67]
6 (Yellow)	Education Policy and Pedagogical Approaches in Environmental Education	4	[68,69]

Source: VOSviewer Co-citation : Cited references analysis

Table 5 encapsulates the findings of the co-citation study, detailing cluster labels, publication counts, and exemplary articles. Consequently, Hypothesis 2 was validated.

5. RESEARCH SIGNIFICANCE

This study analyses the current status of EESD in basic education. By employing bibliometric analysis, it reveals the complexity inherent in the literature system.

5.1 Theoretical significance

This study enhances the theoretical framework of EESD by offering a systematic assessment of the research landscape in this domain. The bibliometric analysis identifies key theoretical frameworks that shape EESD, including interdisciplinary learning, competency-based education, and transformative pedagogy. By mapping the co-citation network, this study highlights foundational works that influence contemporary research, such as Wiek et al. [52] on sustainability competencies and Rieckmann [53] on learning objectives for sustainable development. The findings highlight the importance of integrating EESD into broader educational paradigms, particularly in basic education, as this stage is crucial for fostering students' environmental awareness and sustainability-oriented thinking. EESD extends beyond traditional environmental education toward a more holistic and systemic approach. Additionally, this study reveals emerging research trends, such as the role of digital learning technologies and participatory learning in sustainability education. The theoretical insights derived from this study offer significant direction for subsequent research, assisting scholars in refining conceptual models and aligning EESD more effectively with the SDGs.

5.2 Practical significance

This study's findings have obvious consequences for educators, politicians, curriculum developers, and researchers committed to enhancing the integration of EESD into basic education. By identifying key research clusters and thematic trends, this study provides guidance on best practices for embedding sustainability concepts within environmental educational frameworks. One significant practical contribution is the emphasis on teacher training and professional development, as highlighted by the co-citation analysis.

Ensuring that educators possess the necessary competencies to effectively teach sustainability is essential for the successful implementation of EESD. This study emphasizes the significance of multidisciplinary curricula that integrate environmental education with the social and economic dimensions of sustainability. The policy recommendations derived from this research advocate for institutional support, funding allocation, and policy coordination to enhance the integration of sustainability education across different educational levels. By bridging research findings with classroom practice, this study offers actionable insights to improve the quality and impact of EESD in basic education.

6. CONCLUSION, LIMITATIONS AND PROSPECTS FOR FUTURE RESEARCH

This research conducts a comprehensive bibliometric analysis of EESD in basic education, revealing significant research trends, key theoretical contributions, and practical implications. The findings indicate that as the global sustainable development agenda advances, environmental, resource, and ecological challenges intensify, and the education system increasingly seeks to integrate the SDGs, academic interest in EESD has grown substantially. There is a rising emphasis on interdisciplinary learning, teacher training, and policy integration. The co-word and co-citation analyses highlight the evolving research landscape, underscoring the necessity of competency-based EESD and innovative teaching approaches.

The bibliometric technique predominantly offers quantitative insights and does not facilitate a comprehensive examination of the specific content or context of individual studies. Therefore, future research could complement bibliometric analysis with qualitative systematic reviews to gain a more detailed understanding of the implementation of EESD across different educational contexts. Secondly, while this study identifies gaps between theory and practice, further empirical research is needed to explore how environmental education can effectively develop and assess students' sustainability competencies and thinking in real classroom settings.

Looking ahead, future research should focus on delving deeper into basic education teaching practices to evaluate the effectiveness of different EESD instructional approaches, particularly within diverse cultural and socio-economic contexts. It is also essential to explore effective environmental education teaching methods across various disciplines to better foster students' sustainability thinking and advance the achievement of SDGs. For example, subjects with a strong creative and engaging component, such as art education, may offer unique opportunities for promoting sustainability-oriented learning. Additionally, longitudinal studies are crucial for assessing the long-term impact of environmental education on students' attitudes and behaviors toward sustainability. Given the rapid advancements in information technology and artificial intelligence, another promising research direction is the integration of digital technologies, such as virtual learning environments and AI applications, into EESD. Future research should also examine the implementation of education policies at different levels, analyzing how national and regional policies influence classroom practices. By resolving these research deficiencies, subsequent studies can enhance the theoretical and practical underpinning for the implementation of EESD, ultimately fostering a new generation of learners equipped with sustainability-oriented thinking to tackle global environmental challenges.

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