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Unlocking STEM for environmental sustainability: A bibliometric review of SDG-driven education

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Abstract

This study aims to determine the role of science, technology, engineering, and mathematics (STEM) education in enabling sustainable development from an environmental perspective within the framework of sustainable development goals (SDGs). The Scopus database was analyzed to review peer-reviewed sources published from 2015 to the year 2025 to identify the current trends of research, prominent authors, methodological approaches, and thematic trends in the connection of STEM education and environmental sustainability. The final inclusion criteria were based on the PRISMA screening process, which has identified 78 studies in total out of the 1,227 records initially identified as part of the review process. The findings show that the number of scholars who are interested in the intersection of STEM education and sustainability has increased significantly, especially regarding SDG 7, SDG 12, and SDG 13. Moreover, the study offers suggestions for creating better environments that encourage collaboration to unlock the full potential of STEM education in attaining sustainable development objectives. However, the finding shows that there are significant geographical differences in production and limited integration of interdisciplinary research in certain areas. The study contributes to the literature by providing a broad perspective of the research trend, and the major gaps that would be used in future research. But the results indicate notable geographical disparities in research production and limited integration of interdisciplinary frameworks in some regions. The study contributes to the literature by providing a comprehensive overview of research trends and identifying key gaps that can inform future research, policy development, and educational practices aimed at strengthening the role of STEM education in achieving global sustainability goals.

Keywords: STEM education, environmental sustainability, sustainable development goals, systematic review, bibliometric analysis

INTRODUCTION

Sustainable development has thus attracted considerable international interest, particularly because of increasing environmental concerns such as climate change, resource depletion, and pollution (AlAbidi et al., 2024a; Al-Shetwi, 2022; Klarin, 2018). Solving these issues requires new ideas, which can lead to sustainable development and stable advancement. To steer global processes, the United Nations (UN) adopted the concept of sustainable development in 2015 in the form of sustainable development goals (SDGs), which are characterized by an integrated approach and consist of 17 interrelated goals providing for the conservation of the environment while ensuring social and economic progress (AlAbidi et al., 2024b; Blasi et al., 2022; Leal

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Contribution to the literature

- This research contributes to the literature in both a timely and informative manner, as it maps an evolving area of the STEM education enterprise as related to environmental sustainability and provides a synthesis of patterns, foci, and voids across the SDG agenda.
- Through the use of bibliometric analysis and systematic review, this study delivers an organized evidence base for prospective research and policy.
- The study will encourage further studies to elaborate these general insights through more detailed theoretical and empirical studies on the pathways from STEM education to quantifiable sustainability impacts.

Filho et al., 2019). In this context, sustainable development in education has increasingly become vital as it addresses "societal challenges such as environmental degradation, social inequality, and economic insatiability" (AlAli et al., 2023, p. 2).

Sustainability in education focuses on embedding sustainability principles within the educational practices to address environmental, societal and economic issues (Gamage et al., 2022; Hariram et al., 2023). It helps students gain the necessary knowledge and acquire skills relatable to the 21st century. Numerous research studies have emphasized the importance of integrating sustainability principles into teaching subjects like mathematics, social studies and arts (AlArabi et al., 2025; Hussain et al., 2022). Here, teachers are urged to introduce their students to environmental issues seeking equity and development of the economy. The recent studies have underscored the significance of diversified teaching strategies in the development of education for sustainable development (ESD). For example, López Fernández-Escandón al. (2025) and Taani et al. (2025) showed that the effectiveness of teaching practices in higher education can be varied based on their alignment with sustainability competencies, highlighting the role of interactive, student-centered pedagogies in influencing the development of critical thinking and problem-solving skills. This finding confirms the focus of the present study regarding the necessity to shift to the methods of more integrated and competency-based teaching in science, technology, engineering, and mathematics (STEM) education for sustainability. AlAli et al. (2023) suggest that teachers should engage students in hands-on-activities that reflect real-world issues particularly in relation to sustainability challenges, empowering the students to be responsible citizens and change agents.

In this context, STEM disciplines can be viewed as key, offering the methods, information, and inventive approaches necessary for addressing environmental issues. STEM disciplines actively develop technological solutions to advance sustainable clean energy, resources, and ecological protection, reflecting the goals of several SDGs (Gamage et al., 2022; Hamad et al., 2022; R. Y. Khalil et al., 2023; Vaverková et al., 2024;). Concise and often interdisciplinary STEM research and education provide transformational solutions that advance sustainable environmental, societal, and economic development (AlArabi et al., 2025; Barakabitze et al., 2022; Chen et al., 2019; Rabbani et al., 2023).

However, despite its perceived potential, STEM education's contribution to environmental sustainability remains debatable. Persistent challenges, such as geographic research biases, lack of cross-disciplinary integration, and limited real-world implementation of STEM-driven policies, hinder its full realization (Barakabitze et al., 2019; Hamad et al., 2022). If STEM is the key enabler of sustainable development, stronger frameworks for interdisciplinary collaboration, policy integration, and global accessibility must be established. Otherwise, its role in achieving the SDGs may remain more aspirational than transformational. Therefore, the purpose of this study is on the scientific literature differentiating between STEM education and its less sustainable implementation in the context of the SDGs through an empirical literature review and bibliometric analysis. The study focuses specifically on; Trends in the spread of diverse sciences in the STEM education, determining the most common research undertaken in the previous studies, exploring the economic development objectives that are the most relevant in relation to STEM education, and determining gaps and future research on this area.

PROBLEM STATEMENT

Despite the growing recognition of STEM's potential for development goals, more literature must be reviewed to analyze how particular interdisciplinary STEM programs have helped achieve SDGs in environmental management. This lack of research suggests that a systematic review and bibliometric analysis will map and assess how STEM enhances sustainable practices and their association with SDGs. Through this exploration of cross-disciplinary affairs in STEM, this study aimed to discover how concepts from these disciplines have been utilized to advance sustainability efforts, especially environmental ones.

This study sought to explore the available literature and identify trends, approaches, and themes in research on STEM and environmental sustainability concerning SDGs. In preparing this review, a bibliometric approach

will be used to quantify the breadth and depth of the linkage between STEM and environmental sustainability goals, presenting methodical tones to demonstrate and assess interdisciplinary contributions to advancing the objectives of the SDGs.

Thus, understanding how STEM contributes to environmental sustainability concerning SDGs is essential for policymakers, educators, and researchers to develop new programs and initiatives in the future and ensure that they coincide with global SDGs and objectives. Not only does this study answer a question lacking in the current literature, but it also provides a roadmap to guide the creation of specific policies and educational programs to ensure that STEM has the most significant positive possible impact on society. Future research based on the findings of this review could contribute to the development of a holistic and practical concept of environmental sustainability through STEM. This study focused on exploring the academic literature that relates STEM education and environmental sustainability in the development of the SDGs. In particular, the study sought to determine the publication trends, methodological strategies, research topics, and gaps in knowledge in the literature to have a better understand of how STEM education can be contributes to environmental sustainability. Specifically, this study aims to address the following research questions (RQs):

RQ1. What are scientific publications trends concerning STEM education and environmental sustainability, in terms of the year of publication, the type of document, keywords, and the countries with the most contributions?

RQ2. What are the most frequently used research methods in the studies that addressed the relation between STEM education and environmental sustainability?

RQ3. Which SDGs are the most common concerning literature related to STEM education?

RQ4. How has the impact of STEM education in promoting environmental sustainability evolved in the context of SDGs?

RQ5. What are the gaps in the research and future trends of the studies associated with STEM education and environmental sustainability?

RELATED LITERATURE

STEM Education and Sustainability

STEM education contributes significantly to economic advancement and enhances the competitive advantages since it assists individuals to acquire new skills and competencies leading to meaningful transformations in society (Awad et al., 2025). It has become a necessity to integrate the skills and competencies of STEM education into sustainability to confront the current global issues, i.e., global warming, poverty, desertification and renewable energy.

Across the Gulf Region, countries like the United Arab Emirates (UAE) and Saudi Arabia (SA) are making notable strides in embedding STEM education within their national curricula. In the UAE, STEM for the future' is a program that has been integrated into the school curriculum that emphasizes the application of STEM principles in the educational field (Al Zaabi et al., 2026; Awad et al., 2025). Subsequently, teachers have been targeted in continuous professional development programs by introducing them to teaching strategies that aim to equip them with the strategies to incorporate STEM education to improve students learning experiences (AlArabi et al., 2024; Ibrahim et al., 2023). The "STEM for the future" initiative reflects a growing commitment to equipping students with practical, future-oriented skills. In SA, the Ministry of Education established the National Center for the Development of STEM in 2017, which consists of three levels: scientific-based centers, school-based centers and STEM integration in classrooms. STEM scientific-based centers offer supportive programs during evenings, weekends and summer holidays. A total of thirty-two school-based centers have been established to deliver specialized training. At the third level, STEM is integrated directly into classroom instruction (AlAli et al., 2023). SA has taken a structured approach by establishing a national STEM framework that supports both teachers and learners through specialized centers and classroom integration (Ibrahim et al., 2023). These efforts highlight a regional focus on preparing students for the demands of a rapidly evolving world.

STEM education is increasingly recognized as a catalyst for achieving the UN SDGs (Velempini, 2025), particularly those focused on environmental sustainability—SDG 7 (affordable and clean energy), SDG 12 (responsible consumption and production), SDG 13 (climate action), SDG 14 (life below water), and SDG 15 (life on land).

Education for Clean Energy (SDG 7)

The need for clean energy is intimately linked to contributing to socio-economic development and preserving the world from environmental pollution. The link between education and sustainability of clean energy demands individuals to change their behaviors and lifestyles towards achieving low-carbon footprints (Piao & Managi, 2023). AlAli et al. (2023) shows that countries with higher educational attainment are more likely to maintain and utilize sustainable household practices that improve energy consumption. UNESCO (2021) reported that people with high education, i.e., in Netherlands, tend to use less energy and across ten countries, people with higher education tend to save more water. Thus, significant educational efforts are

needed to equip students with the knowledge and skills needed for making informed decisions as energy consumers. The global energy assessment stresses the importance of offering training programs that focus on how to provide clean energy, particularly in developing countries (Babayomi et al., 2022).

Education for Responsible Consumption (SDG 12)

In order to sustain global greener economies, consumers must increase their awareness about sustainability challenges including greenhouse gas emissions, climate change, biodiversity loss and accountable and sustainable production and consumption (Gunawan et al., 2019). Greenhouse gas emissions are considered a major contributor to global warming. Climate change is an environmental challenge that threatens ecosystems and human livelihoods. Another environmental threat is biodiversity loss which endangers the balance of natural systems. Increased awareness empowers individuals to make informed decisions that align with environmental sustainability, thereby fostering a culture of responsibility and active participation in environmental stewardship (Raman et al., 2024). Without widespread consumer understanding and engagement, efforts to transition to low-carbon, resource-efficient economies may fall short (UNESCO, 2017).

Education to Protect the Planet (SDG 13)

Education plays a key factor in mitigating the impacts of climate change across various domains. Natural disasters and the consequences of climate change that dramatically affect people's lives can be combated if people are well-educated and have high awareness (Tavdgiridze et al., 2024). Education can enlighten people about carbon-friendly practices relatable to technology absorption processes. Students becoming environmental researchers and engineers will contribute to the protection of the planet (Vladimirova & Le Blanc, 2015).

Education for Life Below Water (SDG 14)

It is reported that oceans and seas are essential for national and global economic well-being. The global ocean economic outcome generated by ocean-related activities is estimated to be between US $3 trillion to US $6 trillion, contributing to the world economy in many important ways (Vladimirova & Le Blanc, 2015). Life below water is facing increasing challenges, such as pollution, due to human activities such as exploration and transportation of oil and gas across the oceans and seas. Added to that, oceans and seas are being over-exploited considering the utilization of modern technology and highly resourceful multinational companies, threatening the drainage of marine life (Chatterjee, 2017). Thus, the role of education is vital to draw attention towards saving life below water and preserving marine life for future generations. School and university curriculum are injected with learning experiences that can raise peoples' awareness about marine life and the need to preserve oceans and seas.

Education for Life on Land (SDG 15)

Education is recognized as a powerful tool for raising awareness and shaping new values and attitudes, and promoting behavioral changes towards environmental issues (UNESCO, 2019). Hence, quality education is a necessity for protecting the environment. Studies show that highly educated people demonstrate an increased awareness and concerns about the environment. UNESCO (2021) reports that environmental concerns have increased with education level. For instance, across 29 mostly developed countries, 25% of people without secondary education expressed concern for the environment, compared to 37% of people with secondary education and compared to 46% of those with tertiary education.

By cultivating critical thinking, scientific inquiry, and innovative problem-solving, STEM equips learners with the competencies needed to address global challenges such as carbon emissions, biodiversity loss, ocean pollution, and deforestation. This connection is echoed in global frameworks like UNESCO's (2019) ESD, which promotes integrating sustainability into all levels of education, emphasizing STEM as a tool to foster environmental responsibility and sustainable lifestyles.

METHODOLOGY

The study employed two complementary approaches to ensure a clear alignment between the objectives and the anticipated outcomes of the study:

1. Systematic literature review (SLR): It was through this that previous studies concerning STEM education and environmental sustainability were identified and analyzed in order to find out the trends of research and the major themes related to the SDGs.
2. Bibliometric analysis: This was applied to pattern of scientific publications, including:
   (a) number of publications per year,
   (b) type of documents,
   (c) countries and institutions with the highest contributions, and
   (d) the most used keywords.

The bibliometric analysis was intentionally employed to complement the systematic review by offering a macro level mapping of the field, while the systematic review was a micro level qualitative synthesis of the chosen studies. This integration allowed us to develop a more profound concept of how STEM education helps to

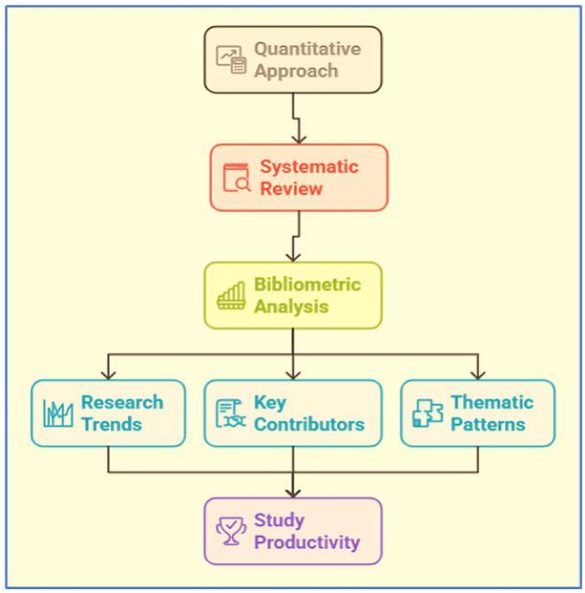

Figure 1. Research design (Source: Authors' own elaboration)

achieve environmental sustainability in the context of SDG. Though the systematic review has provided a detailed qualitative synthesis of the chosen studies, the bibliometric method allowed us to track the prevalent areas of research, emerging themes, or underexplored topics, and then to analyze them in more detail using the systematic review. This two-dimensional strategy ensured that the review is not only synthesizing the available evidence but also placing it in more large-scale research trends, thus contributing to the robustness and comprehensiveness of the study. This dual approach enhances validity of findings by combining quantitative mapping techniques with qualitative synthesis.

Research Design

The study adopts a quantitative approach through a systematic review of literature and bibliometric analysis to understand the contribution of STEM to environmental sustainability and SDGs (**Figure 1**). Through analyses of academic literature, the study presents an overview of this subject area's prevailing research trend, key contributors, and thematic patterns. Simultaneously, bibliometric analysis measures research productivity and evaluates the patterns of publications, key contributors, and thematic shifts (AlAbidi et al., 2024b; Hassan & Duarte, 2024; Nguyen et al., 2021). The bibliometric analysis was performed using the Scopus database because of its broad academic coverage in identifying and assessing the publications related to how STEM could further enhance environmental sustainability in line with SDGs.

Data Source

Scopus database

Scopus was chosen as the primary database because it includes a wide range of journal articles and other scholarly publications and provides a core of high-quality articles in various fields of study (AlAbidi et al., 2024b). As a multidisciplinary database, Scopus provides a wide range of publications as sources for bibliometric analysis, making it possible to obtain publications to research the use of STEM disciplines to achieve environmental sustainability goals in the context of the SDGs. Keywords involved STEM, environmental sustainability, and SDGs, with the relevant filtering options being publication years, document types, and disciplines.

Systematic review

This study employed an SLR. The study's selection criteria were based on its relevance to STEM education and its ability to enhance environmental sustainability from the perspective of the SDGs. The publication dates of these articles range from 2015 to 2025. The literature employs quantitative and qualitative data to provide a comprehensive view of the impact of STEM education and environmental sustainability within the SDGs (Snyder, 2019; Van Laar et al., 2017). To maintain research integrity and capture the findings with minimal bias or high accuracy, this study exclusively included articles from peer-reviewed academic journals. This study excluded observations that addressed topics unrelated to STEM education.

The investigation utilized Scopus as the primary source for articles, with the search query " STEM, environmental sustainability, and SDGs." Relevant synonyms and alternative keywords were also incorporated in the search strategy to cover all the relevant areas. The use of Boolean operators was to broaden the search and obtain more relevant studies that might not employ the same words. The selection of articles for analysis was limited to those published within the past decade, ensuring inclusion of only the most recent and updated information on STEM education. The initial search provided 1227 articles on STEM, environmental sustainability, and SDGs. Nevertheless, only 800 articles fulfilled the mentioned inclusion and exclusion criteria to consider STEM education in enabling sustainable development from an environmental perspective within the framework of SDGs. As a result, only scholarly articles that were pertinent in this study were considered. These 400 studies were later analyzed. Following the data collection, the process of data cleaning, weeding out duplicates, irrelevant records, or studies sourced from non-peer-reviewed journals. This step limits the final dataset to high-quality works concerning the RQs (78

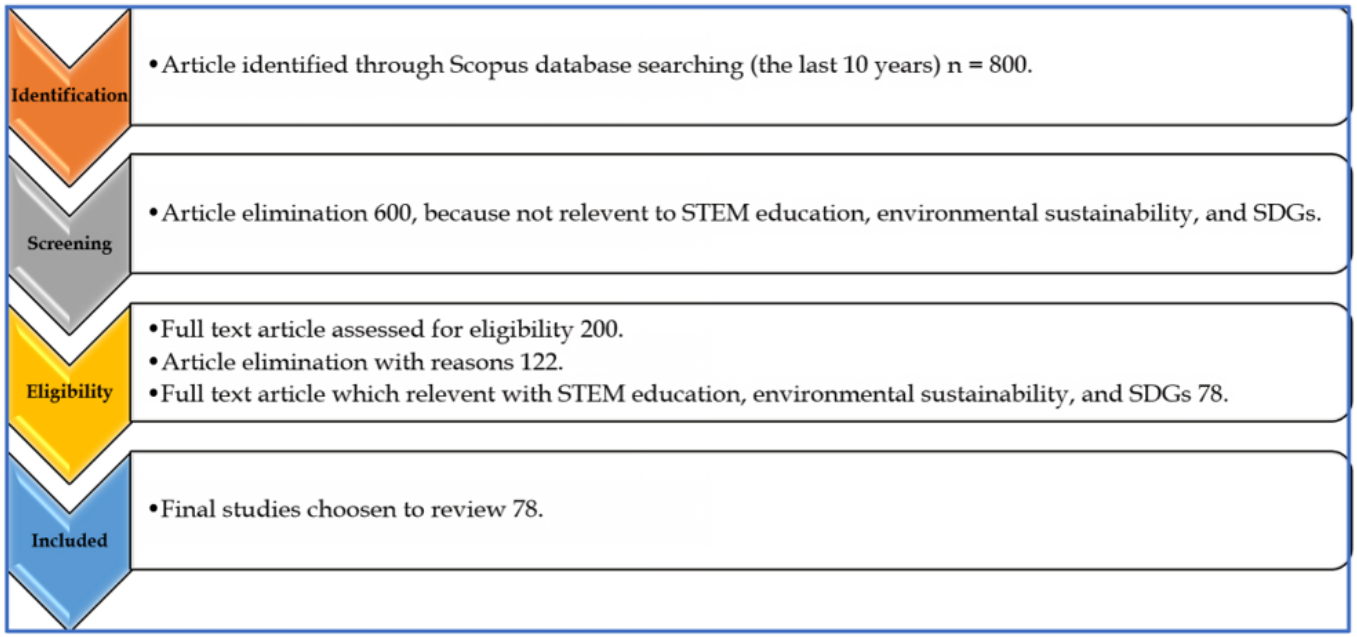

Figure 2. Article selection in stages using the PRISMA model (Source: Authors' own elaboration)

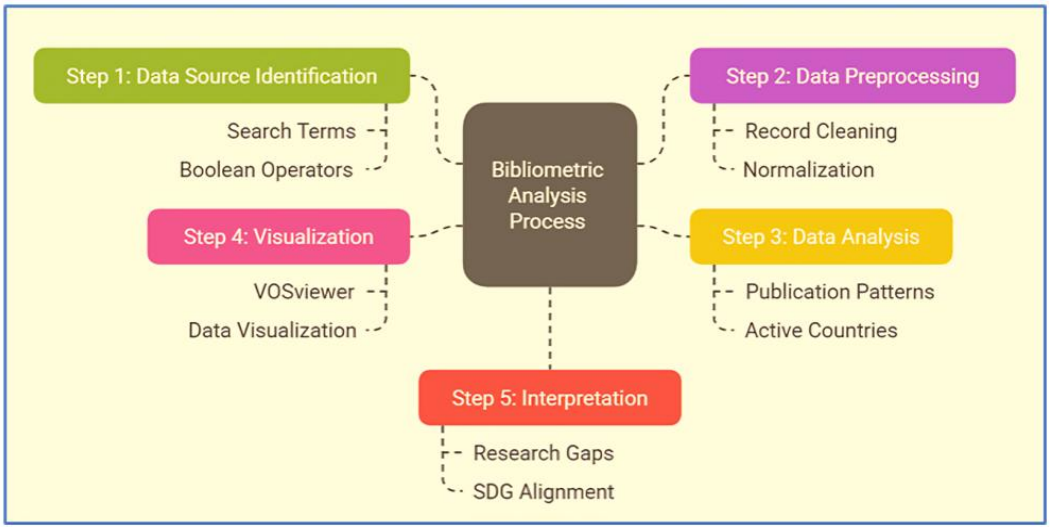

Figure 3. Bibliometric analysis process for STEM and sustainability (Source: Authors' own elaboration)

documents). Only those contributions that had barely related STEM education in enabling sustainable development from an environmental perspective within the framework of SDGs were omitted. This methodological approach is beneficial for achieving the synthesis method as it allows for the omission of articles deemed irrelevant to the study (AlAbidi et al., 2024b; Loureiro et al., 2020; Yung & Khoo-Lattimore, 2019).

Data extraction entailed a systematic review of each study to identify the specific STEM education applied, the learning model employed in the study, and the performance measures utilized for student assessment. This process involved categorizing the studies according to their use of STEM disciplines to achieve environmental sustainability goals in the context of the SDGs. Subsequently, data was collected to facilitate comparative analysis among the studies under examination.

The synthesis method applied in this process was qualitative because the data obtained from the studies were sorted and quantified to identify patterns (Lundblade, 2023). By integrating the results, this study offers an outline and describes the relationships concerning the effects of STEM education on environmental sustainability in the context of the SDGs. PRISMA model (**Figure 2**) was used for identification, screening, eligibility, and inclusion during the selection process (AlAbidi et al., 2024a; Page et al., 2021; Rethlefsen et al., 2021; Selcuk, 2019;). Therefore, this study confined the data and sorted them to highlight the importance of STEM education in attaining environmental sustainability.

Bibliometric analysis procedure

A bibliometric analysis was conducted following five structured steps (**Figure 3**) to ensure a thorough examination of the literature (AlAbidi et al., 2024b; Cheng et al., 2018). The first step was to identify the data source as a precursor to correctly formulate the search terms to help select the materials. Employing Boolean operators for sensitive search, the following search terms were used: "STEM," "environmental sustainability," and " SDGs." The search for articles was restricted to those published in peer-reviewed journals and proceedings within a certain period (the last ten years). Articles in languages other than English were also not considered for data analysis to ensure consistency of the process.

The second step was data preprocessing. To minimize data discrepancies, the obtained records were subjected to record cleaning by eradicating duplicate records and enhancing incomplete entries. Specific fields were normalized for compatibility, including keywords, publication years, and author names. This step ensured that the dataset captured accurate academic output relative to STEM, environmental sustainability, and the SDGs in a way that would allow for a more rigorous analysis.

Third, the preprocessed data were analyzed to extract relevant patterns and trends from the reviewed literature. The nature of publications in this field has also been analyzed by looking at the number of publications per year, the type of documents, and the countries most active in this area. In addition, the analysis was extended to determine prominent sources and authors and their affiliations to understand institutions and regions that are more engaged in studying STEM and its role in environmental sustainability in the context of the SDGs.

Fourth, to aid data interpretation, bibliometric data were visualized using the VOS viewer. Finally, this interpretation highlights the concept of interest, the working frequency of SDGs, and the dominant approaches to connecting STEM with environmental sustainability.

Thus, this kind of analysis highlights opportunities for further contributions, the development of new topics, and research gaps based on analyzing trends in publication indicators, keywords, and citation frequency. Findings were contextualized within the framework of the SDGs, assessing how STEM research aligns with global sustainability objectives and where additional research might contribute further.

LIMITATIONS

Several limitations must be noted in this study, including the following: First, the focus on the Scopus database introduces the potential of missing some sources; not all sources in this area of study are listed in this database, including those that are regional journals or that provide a local perspective on STEM and sustainability. Furthermore, the selected literature review was confined to the last ten years, imposing a constraint based on the period. This could mean excluding primary or prior research conducted years ago, but it is still valuable in understanding the context for current progress. Another methodological limitation is the restriction to English language publications only, which could result in the exclusion of potentially significant research produced in countries or languages other than English, thus reducing the generalizability of the study across the globe. Finally, bibliometric analysis primarily focuses on the number of publications and keyword frequency, which, although valuable, can be less informative compared to qualitative studies, providing deeper insights into STEM's effect on environmental sustainability in terms of various SDG goals.

RESULTS AND DISCUSSION

A Systematic Literature Review

To make sure that the objectives of the study are related to the analysis given, the results of the study were shared as per the RQs. First, the tendency of scientific publications regarding the STEM education and the environmental sustainability was analyzed, such as how many publications are published annually, the type of documents, and the countries with the highest contributions in this field. Second, the methodologies of the previous studies conducted were reviewed to determine the most common approaches in studying the relationship between STEM education and environmental sustainability. Third, the most common SDGs linked to STEM education according to the scientific literature were outlined. Finally, the gaps in research and the future trends in the field were analyzed.

RQ1. This study highlights that interdisciplinary collaboration within STEM fields significantly enhances efforts toward environmental sustainability, aligning closely with SDG objectives. Studies indicate that interdisciplinary approaches facilitate innovative problem solving by integrating knowledge from various scientific and technological domains (AlArabi et al., 2022; Margot & Kettler, 2019; Podgórska & Zdonek, 2023). For example, climate change and environmental management require insights from both the engineering and ecological sciences, enabling the development of sustainable technologies and frameworks (Dwivedi et al., 2021; Nguyen et al., 2020). However, the findings suggest that while interdisciplinary efforts have made strides, there is still a need for more structured collaboration models to ensure that the integration of diverse fields consistently supports sustainability goals across regions (Hariram et al., 2023).

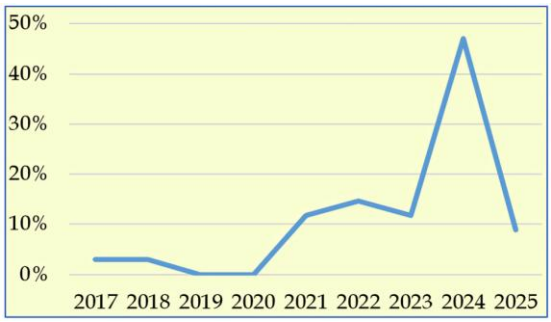

Figure 4. Article publication 2015-2024 (Source: Authors' own elaboration)

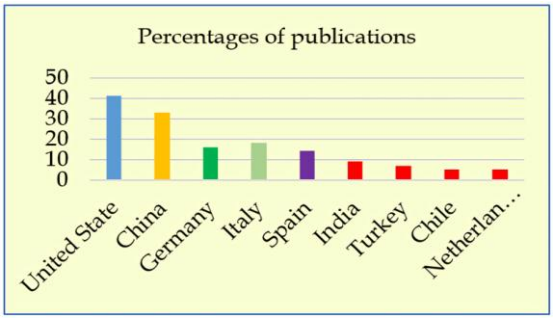

Figure 6. STEM and sustainability study distribution by country (Source: Authors' own elaboration)

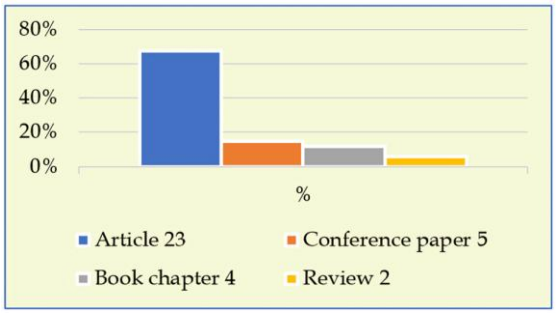

Figure 5. STEM and sustainability study distribution by document type (Source: Authors' own elaboration)

RQ2. The prevalent research methods and analytical approaches in studies linking STEM fields to environmental sustainability goals are a common theme in research on STEM and environmental sustainability, in which bibliometric and statistical methods are used to track STEM's general patterns in publication output, authorship, and geographical distribution (I. A. Khalil et al., 2024). These methods assist researchers in identifying stakeholders and assessing the impact of STEM-related activities on achieving sustainability goals. However, to overcome ethical issues, quantitative research remains essential for evaluating STEM for context and sustainability. The analysis indicates that using both quantitative and qualitative methods could offer a better basis for addressing the challenges of policymaking in this area and the establishing of the right educational programs in STEM fields associated with sustainability.

The growing number of publications on STEM and environmental sustainability, particularly between 2021 and 2024, demonstrates the current level of research in this field (**Figure 4**). Most documents from the Scopus database are peer-reviewed journal articles that are extensively supplemented by conference papers and book chapters (**Figure 5**).

RQ3. The literature mainly focuses on environmental literacy SDGs, such as SDG 13–climate action, SDG 7–affordable and clean energy, and SDG 12–responsible consumption and production (Fonseca et al., 2020; Gunawan et al., 2019). These goals dovetail with STEM's key domains of technology innovation, productivity, and environmental preservation. For instance, the analysis of STEM in renewable energy technologies and resource management demonstrates how STEM can support these SDGs (AlAli et al., 2023). However, research on SDG 10 (reduced inequalities) and SDG 3 (good health and well-being) shows the potential for STEM to become more involved with the aspiration of addressing a wider array of sustainability goals.

RQ4. Regarding the evolution of STEM's role in environmental sustainability, the last few years have seen a significant shift in STEM toward sustainability due to global consciousness and topical policies that promote sustainable development (Gamage et al., 2022). The analysis establishes an increase in STEM articles dealing with SDGs, with trends noted in fields such as climate change modelling, sustainable structures, and green power technology (Del Cerro Velázquez & Lozano Rivas, 2020; Ozge Ogut et al., 2024). This evolution points to a change in STEM research focus, as they became more aligned with sustainability goals than during the earlier three decades. Nevertheless, there is a concern regarding geographical and economic distribution, where developed countries take the upper hand in technological advancements in STEM-based sustainability (Damar, 2024). By contrast, developing countries lag and may benefit from similar mechanisms. **Figure 6** shows that the leading countries actively contributing to the discussion of STEM, environmental sustainability, and SDGs were United States, China, Germany, Italy, and Spain. Other countries, such as India, Turkey, Chile, and the Netherlands, appear to have limited research on STEM, environmental sustainability, and SDGs. These countries' inadequate infrastructure, which impedes their adoption of technologically advanced learning environments, such as STEM in education, may be the cause of this scarcity.

RQ5. Regarding the impact of STEM education and research on SDGs, STEM education enhances key skills relevant to achieving SDGs, including critical thinking, problem-solving, and innovation. Sustainability-focused curricula combined with STEM studies equip learners to solve challenges that affect humanity, including environmental conservation and climate change (Martín-Sánchez et al., 2022). Moreover, the results of this study align with the pedagogical model suggested

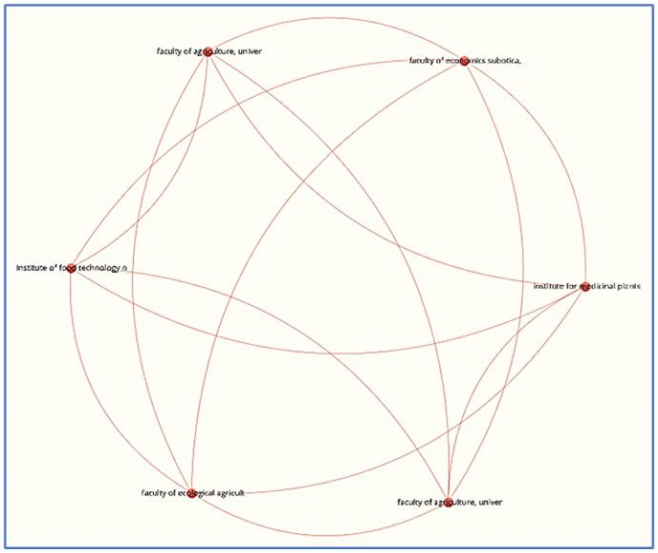

Figure 7. STEM and sustainability study distribution across organizations (Source: Authors' own elaboration, using VOSviewer)

by Auh et al. (2026), according to which STEAM education is a major stimulus of attaining sustainable futures. Their model focuses on the combination of science, technology, engineering, arts, and mathematics to develop holistic and interdisciplinary skills required to handle the complex sustainability challenges. Such a view confirms the significance of implementing the concept of STEAM in STEM learning, as illustrated in the current study, to improve the ability of learners to be innovative, think in a systems manner, and find sustainable solutions to problems. The review further notes that STEM education, when aligned with SDGs, can potentially prepare citizens for sustainable development professions in their lifetime (AlArabi et al., 2024; Chang & Mann, 2024). This alignment also fosters environmentally literate workers; further STEM education reform may breed professionals who care for and act responsibly toward the natural environment (Tikly et al., 2018; Velempini, 2025).

However, several limitations concerning how STEM disciplines incorporate environmental sustainability can still be observed, with special emphasis on interdisciplinarity and geography. The literature review indicates that contemporary research is dominated by some parts of the world and high-income countries, thus masking its generalizability (**Figure 6**). Moreover, a lack of cross-disciplinary theories leads to the acquisition of more holistic solutions (Aguilera et al., 2021; AlAbidi et al., 2023). Future research must fill these gaps by enhancing international cooperation, focusing on understudied areas, and incorporating interdisciplinary theories that may lead to better recommendations for solving key challenges to sustainable development.

Review of Bibliometric Research

To complement the systematic review, a bibliometric analysis was carried out to identify publication trends and research development over the years. The time-span of publications shows that previously (before 2015) the number of publications was comparably low and the literature specifics were more conceptual, more recent research indicate a shift toward empirical investigations and applied educational models. The trend brings out the change of the field to being rather theoretical to implementation-focused research. The bibliometric analysis shows that the growth in the publication output has been evident and has been increasing with time, especially since 2018. This growth aligns with the international support of the SDGs and can be viewed through the interest of scholars in harmonizing STEM education with sustainability agendas (Said et al., 2024). This trend indicates that environmental sustainability STEM education has become a fast growing discipline especially after international policy efforts on sustainable development.

The SLR identified 34 highly relevant articles that addressed the link between STEM education and environmental sustainability in the context of the SDGs. These articles highlight interdisciplinary collaboration, technology, and education improvement, particularly stressing how STEM can help in climate change mitigation, the introduction of clean energy, and responsible resource management. Podgórska and Zdonek (2024), AlAbidi et al. (2024b), and I. A. Khalil et al. (2024) were among the most significant concerning the ability of STEM to facilitate sustainability in theory and practice.

Leading journals published in the STEM-Sustainability Intersection include Sustainability, the International Journal of Learning, Teaching and Educational Research, and Education Sciences, with a clear focus on academic articles by well-known universities such as Berkeley and Cambridge, which carry out advanced research and experiments in STEM and environmental subjects (**Figure 7**). Renowned authors, including Anastas, Botta, Brooks, and Coish, have produced extensive literature on how STEM can enhance achievement, especially in the renewable energy and environmental policy domains.

Key terms in this domain include "environmental sustainability, STEM education, climate action, renewable energy, interdisciplinary collaboration, innovation, sustainable development education, and resource management" (**Figure 8**). These keywords highlight the use of STEM in enhancing sustainability and stress role of STEM education in training students into professionals to address environmental issues.

The most cited papers provided a profound understanding of STEM engagement in sustainability (**Figure 9**). Several recent, highly cited papers by Fonseca

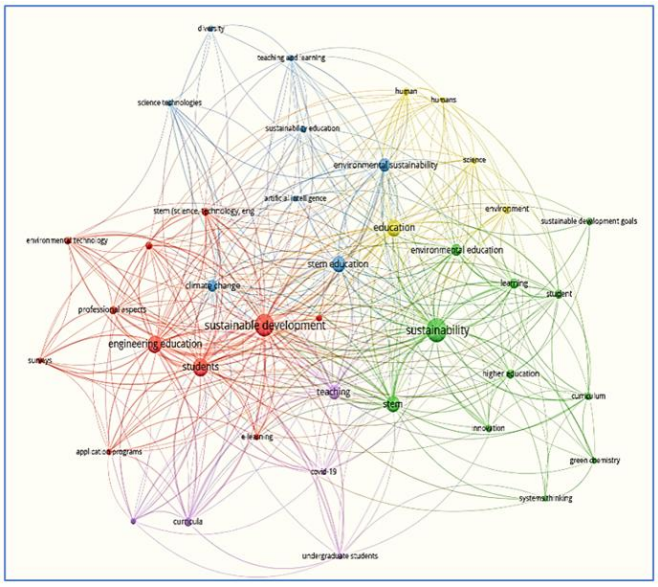

Figure 8. STEM education and sustainability in SDGs articles (Source: Authors' own elaboration, using VOSviewer)

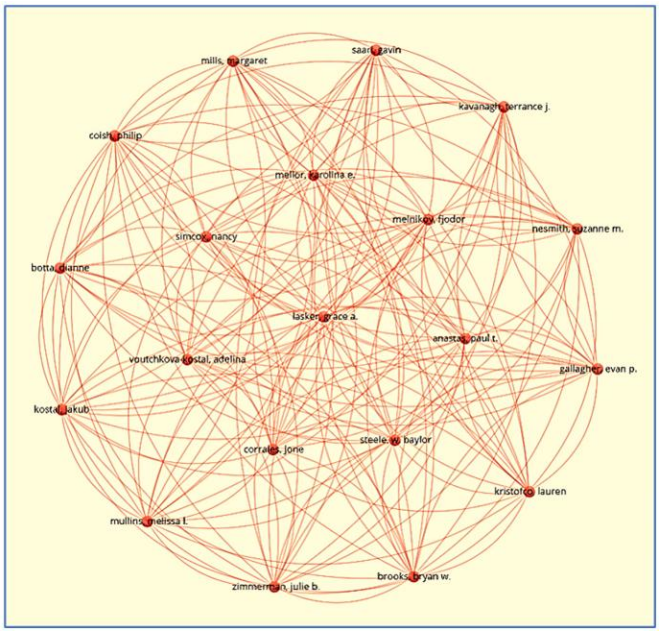

Figure 9. Key authors on STEM and sustainability (Source: Authors' own elaboration, using VOSviewer)

et al. (2020), Gamage et al. (2022), Nguyen et al. (2020), and Martín-Sánchez et al. (2022) demonstrated that STEM education plays a significant role in the improvement of SDGs with the help of technological approaches and interdisciplinary strategies focused on SDGs. Thus, the literature under consideration can be considered an appropriate starting point for future studies and discusses the stake of STEM in advancing sustainability.

Through STEM education, students are equipped with the knowledge, skills, and solutions that help address environmental problems (Abdurrahman et al., 2023; Tavdgiridze et al., 2024).

For example, Cohen et al. (2021) indicated that to achieve the targets of SDG 13 (climate change mitigation), scientific development and innovations in engineering, eliminating emissions, and finding renewable energy resources require STEM knowledge. STEM education also fosters collaboration (Eugenijus, 2023), which is crucial when addressing SGD-related elements encompassing various aspects of sustainability, particularly SDG 6. In STEM projects, research programs, or partnerships, one knows how his/her work may contribute to supporting sustainable activities worldwide (Eugenijus, 2023; Tavdgiridze et al., 2024). Furthermore, STEM enhances technological development among the key sustainability drivers (Choueiri & Choueiri, 2023). The need for the technological aspect can be seen in many SDG goals, such as SDG 2, achieving zero hunger and sustainable agriculture, and SDG 11, ensuring the sustainable use of resources through efficient urbanization. Thus, STEM education is concerned with an adaptive, solution-oriented worldview that helps learners achieve SDGs at the career level and meets sustainable development demands.

STEM, environmental sustainability, and other SDGs are interconnected because STEM fields offer basic understanding, technologies, and approaches to address various environmental challenges. For example, the paradigmatic case of SDG 13 (climate action) is fundamentally based on applying engineering and technology to address climate change issues, such as generating clean energy or constructing better climate prediction models (Hauashdh et al., 2024). Similarly, SDG 7 (affordable and clean energy) is an area that can greatly benefit from STEM developments in solar, wind, and bio-energy systems to make sustainable energy more widespread and affordable (Blair et al., 2021). In addition, the connection of SDG 12 (responsible consumption and oroduction) with STEM pertains to sustainable management of resources: innovations in waste minimization, recycling, and enhancing resource efficiency in manufacturing (Raman et al., 2024). STEM education also contributes to achieving these goals by providing students with sustainability-oriented knowledge and skills to help the next generation cope with environmental issues. Through these co-related activities, STEM enables and propels the advancement of various SDGs, demonstrating why STEM education is crucial for establishing sustainable societies.

Despite the growth and thematic expansion being observed, the bibliometric analysis reveals several critical research gaps. First, it has a low focus on the measurable learning outcomes, especially in terms of building the sustainability competencies. There is numerous research on instructional methods without systematically evaluating their effectiveness on students learning. Second, there is a noticeable of studies on more

advanced pedagogical frameworks, such as the incorporation of AI-enhanced learning environment and STEAM-based models in sustainability education. Finally, the review of the literature demonstrates a scarcity of cross-contextual and longitudinal studies, which restricts the possibility to generalize findings to other educational systems and evaluating the long-term educational effects. These gaps point out important directions for future research and provide a foundation for interpreting the findings of the systematic review.

CHALLENGES

The literature offers several areas for improvement that hinder the understanding of STEM for environmentally sustainable development within SDGs. One primary concern is the challenge of integrating interdisciplinary research approaches to address environmental sustainability issues, as environmental protection often integrates knowledge from various fields including engineering, environmental sciences, social sciences, and policy. This makes research integration and coherence an issue, because there are few formal avenues for cross-disciplinary engagement and cooperation. Moreover, data relevant to establishing connections between STEM and sustainability are often homogeneous or restricted to certain areas of study (Mullen & Klimaitis, 2019). Studies on STEM's effects are skewed toward high-income regions (Fan et al., 2023; O'Farrell & Rawdanowicz, 2017). Therefore, there is a need to understand how STEM-based sustainable development initiatives function or can be implemented in low-income and middle-income countries. These challenges highlight the need for more global research and better interdisciplinary theories to realize STEM's full potential of STEM in attaining the environmental sustainability agenda from the SDG perspective.

IMPLICATIONS

The integration of bibliometric analysis with systematic review findings provides important implications for both research and practice. Regarding research, gaps found imply that further research is required to address the gaps listed, in which the sustainability-related learning outcomes should be empirically measured and innovative pedagogical models can be studied. Practically, teachers are proposed to use various and interdisciplinary methods of teaching, such as STEAM-based models, to help adjust STEM education to the SDGs. Considering the incremented value of integrating sustainability principles into STEM education, it becomes imperative that making this integration is an indispensable part of mainstream education. This approach will help students develop various skills and competencies such as creativity, critical thinking and problem solving. Involving students in hands-on activities and project-based learning is likely to improve their learning styles.

In relation to educational institutions, sustainability practices can be implemented by transforming the structure of school buildings into eco-friendly designs that aim to conserve energy consumption and reduce waste hoping to serve the broader community. Educational institutions should invest in sustainable education that encourages teachers, students, and leaders to contribute to conserving natural resources.

CONCLUSION

This study underscores the contextual significance of STEM education and research in promoting environmental sustainability within the context of the revised SDG framework. The bibliometric analysis also highlights the trends in publishing and collaboration to identify the areas where research is actively taking place, and to find specific SDGs that are often cut across STEM domains. The findings further show that STEM education could be used effectively to produce technological resolutions and foster innovation to address global environmental challenges. Moreover, the study has found that the dominance of a limited number of developed countries in scientific output in this field, thus the necessity of increasing research input by the developing countries. In addition, the results reveal that further interdisciplinary research is necessary to enhance the concept of the integration of STEM education and environmental sustainability. Subsequent research focusing on these barriers should extend the study to collect data from different clients, populations, and cultures. These findings can be used in influencing educational and research policies to be more effective in integrating STEM education into achieving the SDGs, thus leading to a more sustainable and resilient world in the long run.

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AI statement: The authors stated that no generative artificial intelligence (AI) or AI-assisted tools were used in the design, analysis, or interpretation of this study. AI tools may have been used in a limited capacity to support language refinement and editing; however, all content, interpretations, and conclusions were developed by the authors, who take full responsibility for the integrity and accuracy of the work.

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