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The role of mathematics education in shaping sustainable futures: A systematic literature review

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Abstract

The integration of Sustainable Development Goals (SDGs) into mathematics education has gained increasing attention in recent years. This study systematically reviews how mathematics contributes to sustainability and aligns with the SDGs. A systematic literature review (SLR) was conducted following the PRISMA guidelines, analysing 31 studies published between 2019 and 2024 from databases such as EBSCO, ERIC, ProQuest, and Taylor & Francis. Content analysis identified key themes, including the SDGs addressed, educational levels, and research methodologies. The findings indicate that most studies focus on SDG 4 (Quality Education) and SDG 13 (Climate Action), primarily in primary and secondary schools. Qualitative and mixed-methods approaches are commonly used, with project-based learning as a frequently applied instructional model. The review confirms that mathematics education plays a vital role in fostering critical thinking, problem-solving, and sustainability awareness. However, challenges persist in terms of curriculum development and teacher training. Future research should explore interdisciplinary approaches and expand the integration of diverse SDGs into mathematics education to strengthen its role in addressing global sustainability challenges.

Keywords: education for sustainable development; mathematics education; SDGs; systematic review

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Introduction

The Sustainable Development Goals (SDGs) are a global framework introduced by the United Nations (UN) in 2015 with the main objective of addressing the fundamental challenges faced by humanity and the planet through 17 goals and 169 detailed targets (UN, 2015). These goals cover a wide range of critical issues, such as the eradication of poverty, achieving gender equality, providing quality education, addressing climate change, and fostering sustainable urban development (UNESCO, 2017; Semiz & Baykal, 2020).

The SDGs emphasize the interconnectedness of these global challenges and support the search for holistic, inclusive, and sustainable solutions. Education, which is the focus of Goal 4, is considered a transformative force for achieving sustainability by providing individuals with the knowledge and skills needed to tackle the increasingly complex environmental, social, and economic challenges (Laurie et al., 2016). Although the 2030 Agenda calls for urgent action, achieving these ambitious goals remains a major challenge that requires active collaboration between governments, educators, civil society, and the private sector (Otto et al., 2019; Figueira et al., 2018). As both a call to action and a framework, the SDGs integrate sustainability principles across various aspects of human life, with education playing a pivotal role in their long term success.

To support the achievement of the SDGs, Education for Sustainable Development (ESD) has emerged as a vital educational framework for integrating sustainability principles into teaching and learning processes (UNESCO, 2017). ESD aims to equip learners with the ability to make informed decisions and take responsible actions, considering the balance between environmental preservation, economic sustainability, and social justice for both present and future generations (Barwell, 2013; Li & Tsai, 2022). This approach emphasizes the importance of participatory, interdisciplinary learning processes that foster critical thinking, collaboration, and systems-based problem-solving (Laurie et al., 2016). Recent developments highlight the need for an ethical foundation in ESD-based mathematics education. Integrating ethical reflection into mathematics instruction can transform students' role as critical agents of sustainability, promoting both moral reasoning and social justice in classroom contexts (Çibik & Boz-Yaman, 2025). In addition, designing learning environments that are both context-aware and socially responsive, particularly in relation to marginalized communities and diverse identities, requires deep reflexivity and inclusivity in mathematics classrooms (Makramalla et al., 2025). Given the importance of transforming educational systems, the UN's Decade of Education for Sustainable Development (2005-2014) laid the foundation for integrating ESD into curricula, educational policies, and teacher training programs (UNESCO, 2017; Bamber et al., 2016). However, the implementation of ESD in classrooms still faces various challenges, particularly regarding the imbalance in its implementation across different educational levels and subjects (Summers, 2013). Despite these challenges, ESD remains a crucial foundation for fostering sustainability, as it encourages learners to critically understand global issues, develop lifelong learning skills, and act as agents of change in society (Renert, 2011; Oral & Erkilic, 2022).

Mathematics education holds a strategic position in supporting the achievement of ESD goals, given its potential to develop critical and quantitative thinking skills needed to address sustainability challenges. As a discipline, mathematics provides tools for learners to analyze complex systems, model real-world problems, and make data- driven decisions essential components for understanding and solving sustainability issues (Alsina & Mulà, 2019; Vásquez et al., 2021). For example, through mathematical concepts such as algebra, statistics, and calculus, students can explore problems like resource optimization, environmental impact assessment, and fair distribution of goods (Barwell, 2013; Su et al., 2022). Incorporating themes related to the Sustainable Development Goals (SDGs) into the mathematics curriculum enables students to connect their learning with pressing global challenges such as climate change, economic disparity, and population growth (Laurie et al., 2016; Semiz & Baykal, 2020). Nonetheless, traditional methods of teaching mathematics often emphasize abstract problem-solving without tying concepts to real-world applications, which can hinder students from relating mathematics to everyday issues (Renert, 2011).

To overcome this limitation, innovative teaching strategies like problem-based learning and project-based learning have been proposed as effective ways to foster active participation and interdisciplinary thinking (Alsina & Mulà, 2019; Oral & Erkilic, 2022). Integrating ESD through collaborative learning models such as Jigsaw significantly improved students' mathematical problem-solving abilities compared to conventional approaches, underscoring the practical impact of ESD-aligned instruction in classroom settings (Shobah et al., 2025; Putra et al., 2025)**.** In this regard, educators hold a pivotal role in promoting sustainability and integrating its principles into students' educational experiences. Discussions on Teacher Education for Sustainability (TEfS) highlight the need to adequately prepare both pre- and in-service teachers to address these demands (Álvarez Ariza & Olatunde-Aiyedun, 2024**).** Integrating mathematical modelling with ESD principles in teacher education programs significantly enhances pre-service teachers' understanding of sustainability issues and strengthens their modeling competencies (Bulut & Borromeo, 2025). By reshaping the role of mathematics education within the context of Education for Sustainable Development (ESD), teachers can equip students with the skills to apply mathematical reasoning in advancing sustainable development goals.

Integrating ESD into mathematics education requires deliberate and planned efforts to align teaching practices with sustainability goals. This includes not only incorporating SDG related contexts into lesson plans but also fostering interdisciplinary mindsets among educators and students (Laurie et al., 2016; Vásquez et al., 2021). For example, students could conduct research on the carbon footprint of specific industries, analyze statistical data related to global poverty, or model the impact of renewable energy usage using mathematical tools (Alsina & Mulà, 2019; Su et al., 2022). Additionally, teacher training is essential for this integration, as educators need the skills and resources to design lessons that effectively link mathematical concepts to sustainability issues (UNESCO, 2017; Bamber et al., 2016). Despite some progress, research indicates that ESD integration in mathematics education remains underexplored, particularly at secondary and higher education levels (Oral & Erkilic, 2022). Recent studies further emphasize this gap, calling for critical pragmatism to guide curriculum design and

teaching practices. A three-step strategy ethical classroom foundations, ethnomathematics integration, and complex problem-solving has been proposed to address these pedagogical challenges effectively (Müller, 2025). This highlights the need for a systematic review of existing knowledge, identifying gaps to be filled, and developing strategies to accelerate the implementation of ESD in mathematics education. By leveraging the potential of mathematics education, educators and policymakers can play a key role in shaping a more sustainable future.

The integration of Education for Sustainable Development (ESD) into mathematics education presents considerable opportunities, yet its practical application and impact across different educational settings remain underexplored. Understanding the process of embedding the Sustainable Development Goals (SDGs) into the mathematics curriculum, along with the obstacles encountered, is essential. Recognizing the value of research that supports the alignment of mathematics education with ESD is equally important. In this regard, recent review studies are beginning to highlight and synthesize findings on the connections between mathematics education and sustainability.

In the field of mathematics education, Álvarez and Olatunde-Aiyedun (2024) conducted a literature review spanning the years 2010 to 2023, focusing on effective strategies to incorporate ESD into the preparation and professional development of mathematics educators. Their analysis of 32 studies highlighted that while mathematics and statistics education are promising avenues for fostering ESD, many educators still exhibit limited understanding and hesitation toward this integration. Consequently, training programs, both initial and ongoing must prioritize actionable examples and engage teachers to overcome these barriers. To support mathematics educators in becoming agents of social transformation and helping students acquire sustainability competencies, further exploration of studies combining mathematics, statistics, and ESD is essential (Li & Tsai, 2022; Semiz & Baykal, 2020). This research seeks to systematically examine the existing body of work on applying SDGs or ESD principles in mathematics education.

This study aims to uncover significant trends and insights related to embedding SDGs into mathematics education within various contexts. It endeavors to map the current state of research, identify prevalent teaching models, and explore scenarios where mathematics education promotes sustainable development. To achieve these objectives, two primary research questions were formulated (Table 1): (a) documentary aspects to analyze publication years, topics, geographic distribution (country of residence of the first author), journal rankings, and research methods, and (b) pedagogical dimensions to evaluate the targeted SDGs, educational levels, sustainability challenges, and keywords.

Table 1. Research questions and initial coding

Areas	Research Questions	Initial Coding
Documentary characteristics	RQ1. What is the distribution of articles by journal and their ranking in the database?	Year of publication and quartile of the journal
	RQ2. What is the geographical distribution of the studies?	Country where the first author of the article resides

Areas	Research Questions	Initial Coding
	RQ3. What research methodologies are developed in the publications and, if any, what are the sample sizes?	Experimental/questionnaire/case study/mixed designs etc.
	RQ4. To which SDGs does the research contribute, and how are these linked to mathematics content?	SDG and content of mathematics
Pedagogical dimension	RQ5. At which educational levels and subjects do the selected studies take place?	Educational levels and research subjects
	RQ6. What are the most trending keywords, and how do they correlate with the publication years?	Keywords in articles, and frequency of their appearance over the years

By exploring these questions, this study aims to make a significant contribution to the understanding of how the Sustainable Development Goals (SDGs) are applied within mathematics education. In the following sections, we will present the methods used to conduct the systematic literature review, along with the results of the data extraction. We will also discuss the findings by addressing the seven research questions. This systematic review is expected to provide insights and encourage critical reflection on how sustainability and sustainable development can be integrated into educational programs, particularly for all stakeholders involved in mathematics education, ultimately fostering positive change within educational environments.

Methods

This research applies a systematic literature review (SLR) approach, following the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines outlined by Page et al. (2021). Through this method, the study aims to conduct an in-depth analysis of existing research on mathematics education and its connection to the Sustainable Development Goals (SDGs). The process is structured based on the methodology described by Petersen et al. (2015), which involves six key steps: (1) formulating research questions, (2) identifying relevant articles, (3) screening and selecting suitable studies, (4) extracting critical data, (5) synthesizing and organizing the information, and (6) ensuring data validity.

To build a robust dataset, journal articles were sourced from four major databases: Ebsco, Eric, ProQuest, and Taylor & Francis. These databases were chosen for their extensive coverage of educational research, access to high quality peer-reviewed journals, and relevance to topics related to mathematics education and sustainability. Each step of this process adhered to PRISMA's evidence-based standards, ensuring consistency and reliability in reporting. Figures 1 and 2 demonstrate the PRISMA flow diagram adapted for this systematic review.

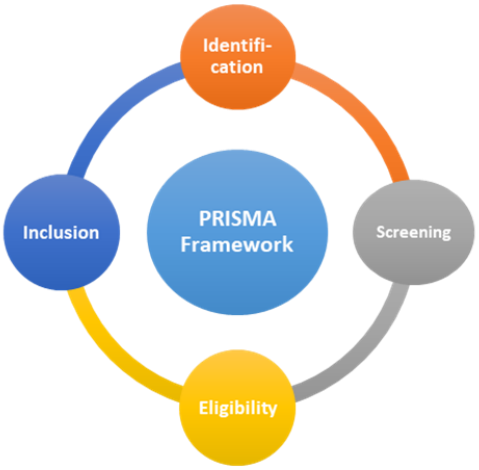

Figure 1. PRISMA framework (Page et al., 2021)

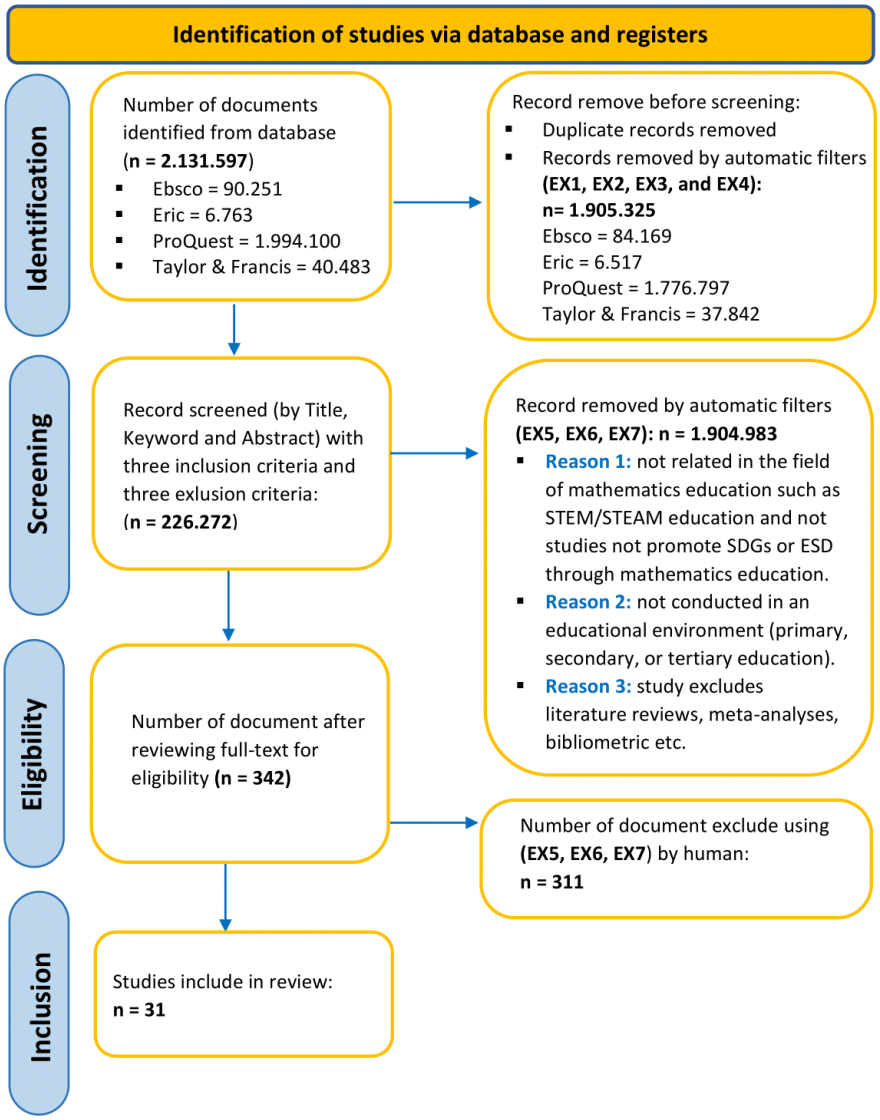

Figure 2. PRISMA framework (Page et al., 2021)

Search and selection of papers

This systematic literature review involved a targeted search for articles published from 2019 to 2024 using four electronic databases: Ebsco, Eric, ProQuest, and Taylor & Francis. The search utilized specific string queries and followed the inclusion and exclusion criteria detailed in Table 2. These databases were chosen for their globally acknowledged impact factors and their comprehensive collections of peer-reviewed academic and scientific literature spanning various fields and disciplines.

Table 2. Information source and searching criteria for the SLR

Information Source	Aspect	Description
Ebsco, Eric, Proquest, Taylor & francis	Timeframe	2019-2024
	Searching strings	Ebsco-Eric-Proquest-Taylor & francis: TITLE-ABS-KEY=((“education for sustainable development” OR “sustainable development goals”) AND (“mathematics education” OR “mathematics”) AND (“students”))
	Inclusion criteria	**IC1:** Journal articles. **IC2:** The study is written in English. **IC3:** The study is not listed in another database. **IC4:** The full text of the study is available**.** **IC5:** The study is related field in mathematics education and to promote SDGs or ESD through mathematics education. **IC6:** The study was conducted in an educational environment (primary, secondary, or tertiary education). **IC7:** The study includes empirical research, case studies, innovations and new technologies, training and curriculum development.
	Exclusion criteria	**EX1:** Proceedings of congresses, conference papers, books, book chapters, and other nonpeer-reviewed publications. **EX2:** The study is not written in English. **EX3:** The study is listed in another database. **EX4:** The full text of the study is not available. **EX5:** The study is not related in the field of mathematics education and to promote SDGs or ESD through mathematics education. **EX6:** The study was not conducted in an educational environment (primary, secondary, or tertiary education). **EX7:** The study excludes literature reviews, meta-analyses, bibliometric analyses.

The systematic literature review conducted in this study adhered to the PRISMA model, ensuring transparency and rigor in identifying, screening, and selecting relevant studies. The process was carried out in four key stages, as detailed below:

1. Identification

During the identification stage, a total of 2,131,597 documents were retrieved from four major databases: Ebsco (90,251), Eric (6,763), ProQuest (1,994,100), and Taylor & Francis (40,483). These databases were chosen for their broad coverage of peer-reviewed journals and their relevance to education and sustainable development. The search terms used included "education for sustainable development," "sustainable development goals," "mathematics education," and "students," combined using logical operators such as "AND." At this stage, duplicate records and irrelevant documents were removed using automatic filters based on predefined exclusion criteria. Specifically, documents were excluded if they were non-peer-reviewed publications such as proceedings or book chapters (EX1), not written in English (EX2), duplicates found across multiple databases (EX3), or if the full text was unavailable (EX4). After this stage, 226,272 records remained for further analysis.

2. Screening

In the screening stage, the titles, keywords, and abstracts of these 226,272 documents were reviewed to identify those most relevant to the research objectives. Automatic filters were applied to exclude studies unrelated to mathematics education or not promoting sustainable development goals (SDGs) or education for sustainable development (ESD) (EX5). Additionally, studies conducted outside of formal educational environments, such as primary, secondary, or tertiary education, were excluded (EX6). Studies that were literature reviews, meta-analyses, or bibliometric analyses were also removed (EX7). As a result of this filtering, 1,904,983 documents were excluded, leaving 342 studies for eligibility assessment.

3. Eligibility

The eligibility stage involved a thorough review of the full texts of these 342 studies to ensure alignment with the research objectives. Studies that failed to meet the inclusion criteria, such as those unrelated to mathematics education or not addressing SDGs/ESD (EX5), those conducted outside formal education settings (EX6), or those lacking empirical focus (EX7), were excluded during this stage. This manual process narrowed the selection further, resulting in 31 studies that satisfied all inclusion criteria.

4. Inclusion

Finally, in the inclusion stage, these 31 studies underwent a final assessment to confirm their relevance and quality. Each study was evaluated to ensure it contributed to the understanding of how mathematics education supports SDGs and ESD. These studies represent a diverse set of perspectives and provide significant insights, forming the foundation of this systematic literature review.

Coding and analysis strategy

To systematically address the research questions, a structured coding framework was developed to categorize articles based on key factors, including the year of publication, geographical region, mathematical topics, research issues, learning outcomes, research approaches, keyword analysis, and links to SDGs. These factors were adapted from previous systematic reviews and aligned with the study's objectives to ensure a comprehensive analysis.

The coding process was conducted by the lead researcher using a detailed manual that provided clear definitions for each category, ensuring consistency and minimizing ambiguity. While formal interrater reliability testing was not performed, the framework was refined iteratively by referencing established literature. Regular self-checks were conducted throughout the process to reduce bias and maintain alignment with the research objectives, enabling a robust examination of trends and methodologies in mathematics education and their connection to sustainability goals.

Results

The study's results present the key findings from the literature review on sustainable mathematics education. After screening and analyzing the selected studies, several main themes emerged, including the incorporation of sustainability in teaching practices, curriculum design, and the involvement of various stakeholders. These results provide insights into current trends and challenges in integrating sustainability into mathematics education.

Distribution of articles by journal and ranking

The systematic review reveals a strong concentration of research on mathematics education for sustainable development in high-ranking journals. Specifically, 29% of the articles are published in Q1 journals, 59% in Q2 journals, 6% in Q3 journals, and the remaining 6% in non-indexed journals. The breakdown of journals and their respective quartiles is presented in Table 3, which illustrates the distribution of articles across different outlets.

Table 3. Information source and searching criteria for the SLR

Journal	Quartile	Articles	Percent
Sustainability	Q1	8	26%
Education Sciences	Q2	4	13%
Mathematics	Q2	3	10%
EURASIA Journal of Mathematics, Science and Technology Education	Q2	3	10%
Research in Mathematics Education	Q2	3	10%
Journal on Mathematics Education	Q2	2	7%
International Journal of Mathematical Education in Science and Technology	Q2	1	3%
Mathematics Teaching Research Journal	Q3	1	3%
Eurasian Journal of Educational Research	Q3	1	3%
Environmental Education Research	Q1	1	3%

Journal	Quartile	Articles	Percent
Avances de investigación en educación matemática	Q2	1	3%
Dialogic Pedagogy	Q2	1	3%
Acta Didactica Napocensia	-	1	3%
Discourse and communication for sustainable education	-	1	3%

The Q1 journal *Sustainability* is the leading contributor, representing 26% of the articles, including studies on sustainability competencies and reflective learning models. *Environmental Education Research* contributes 3%, with research on ESD in teacher development. Among Q2 journals, *Education Sciences* accounts for 13%, while *Mathematics*, *EURASIA Journal of Mathematics, Science and Technology Education*, and *Research in Mathematics Education* each contribute 10%. Studies in these journals explore statistical literacy and curriculum alignment with sustainability. *Journal on Mathematics Education* contributes 7%, focusing on numeracy tasks for SDGs. Q3 journals, including *Mathematics Teaching Research Journal* and *Eurasian Journal of Educational Research*, collectively account for 6%, offering insights into teacher practices. Non-indexed journals, such as *Acta Didactica Napocensia*, contribute another 6%, providing localized perspectives. This distribution underscores the prominence of mathematics education for sustainability research in Q1 and Q2 journals, with Q3 and non-indexed journals adding practical insights.

Years and geographical distribution of the studies

The trend of publications (Figure 3) over the years shows a fluctuating pattern. Starting with only 2 articles in 2019, there was a gradual increase in 2020 (5 articles) and 2021 (6 articles). The number of studies peaked in 2022 with 10 publications, demonstrating the growing interest in the research area during that period. However, the following years, 2023 and 2024, saw a decline, stabilizing at 4 publications each year. This recent decline might reflect either a shift in research priorities or a saturation in specific aspects of the topic.

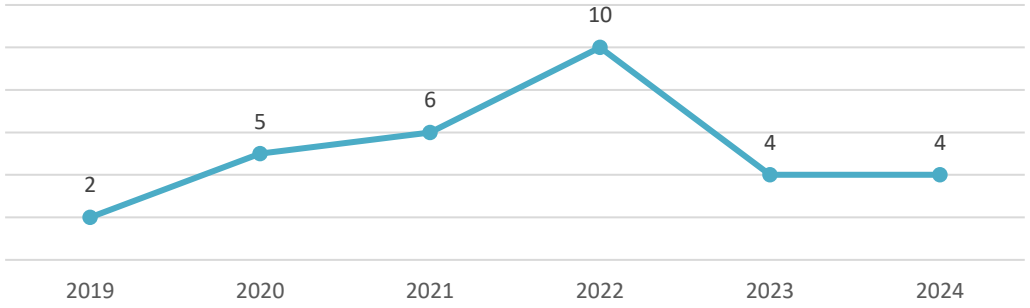

Figure 3. Distribution of studies by year

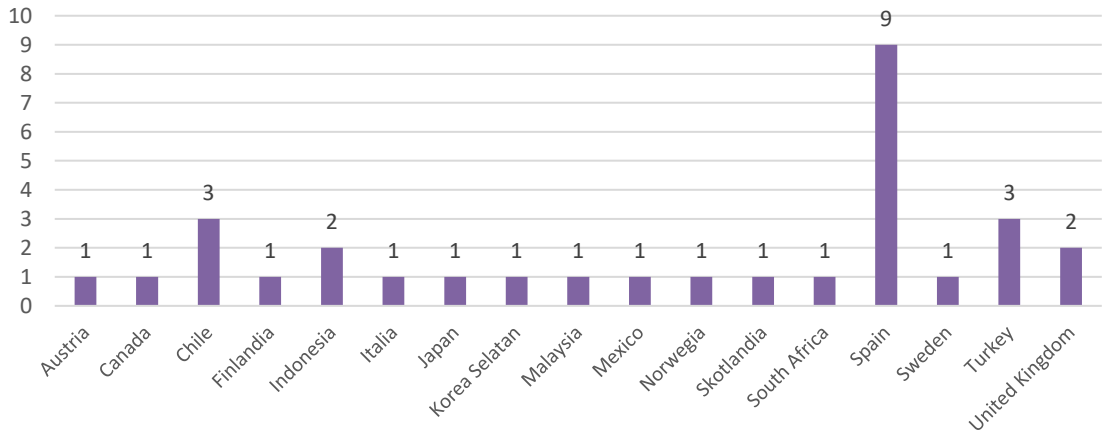

Figure 4. Geographical distribution of the studies

The studies analyzed in this research span across 17 countries (Figure 4), highlighting the global reach and diversity of contributions to the field of sustainable development in mathematics education. Spain is the leading country, with 9 studies, indicating its prominent role in advancing research in this area. In comparison, Turkey, Chile, and Indonesia contribute moderately, with 3 studies from Turkey and Chile, and 2 studies from Indonesia. Several other countries, including Austria, Canada, Finland, Italy, Japan, South Korea, Malaysia, Mexico, Norway, Scotland, South Africa, and Sweden, each contributed only one study, reflecting limited engagement with the topic.

This distribution suggests that Spain is the central hub for research in this domain, while other countries exhibit a scattered presence. The concentration of studies in Spain and a few other countries may stem from institutional or academic priorities in sustainable development and mathematics education. Conversely, the lower contributions from the remaining countries could indicate that these regions are still in the early stages of developing research in this area. In conclusion, the geographical spread of the studies demonstrates both concentrated efforts in certain countries, particularly Spain, and nascent contributions from others, highlighting the varying levels of engagement and focus on sustainable development in mathematics education across the globe.

Research methodologies

A variety of research methodologies has been utilized to explore the integration of Sustainable Development Goals (SDGs) into mathematics education. The most prominent among these based on Table 4 and Figure 5 is the qualitative research design, featured in 12 studies, indicating a strong emphasis on understanding the contextual and nuanced aspects of SDG implementation within learning environments. This approach prioritizes in-depth exploration of educational phenomena, aligning with the goal of fostering sustainable practices in teaching and learning. The case study methodology, utilized in 6 studies, also emerges as a key approach, offering detailed examinations of specific educational settings. For instance, studies by Alsina and Mulà (2019) and Moreno-Pino et al. (2022) demonstrate how localized contexts shape the adoption and effectiveness of sustainability-focused mathematics education. These findings

underscore the necessity of adapting pedagogical strategies to address diverse educational landscapes.

Table 4. Research methodologies used in the studies

Method	Authors/Year
Action research	Helliwell and Ng (2022)
A longitudinal study	Boeve-de Pauw et al. (2022)
Content analysis	Moreno-Pino et al. (2021), Vásquez et al. (2021), Vásquez et al. (2022)
Qualitative research design	Albano et al. (2022), Carmona-Medeiro and Cardeñoso (2021), Domínguez-González and Delgado-Martín (2022), Lafuente-Lechuga et al. (2020), Listiawati et al. (2023), Naidoo and Reddy (2023), Özdemir and Kılıç (2023) Santamaría-Cárdaba et al. (2021), Semiz and Baykal (2020), Su et al. (2022), Tesfamicael and Enge (2024)
Collaborative approach	Solares-Rojas et al. (2022)
Design research	Sari et al. (2024)
Literature-based approach	Summer (2020), Li and Tsai (2021)
Mixed method	Kim and Pang (2022), Suh et al. (2020) Franco Seguí et al. (2024), Joutsenlahti and Perkkilä (2024)
Narrative analysis	Helliwell et al. (2023)
Case study	Alsina and Mulà (2019), Moreno-Pino et al. (2022), Özdemir (2021), Chin et al. (2019), le Roux et al. (2022)
Multi-Criteria Decision Analysis (MCDA)	Jeong and González-Gómez (2020)

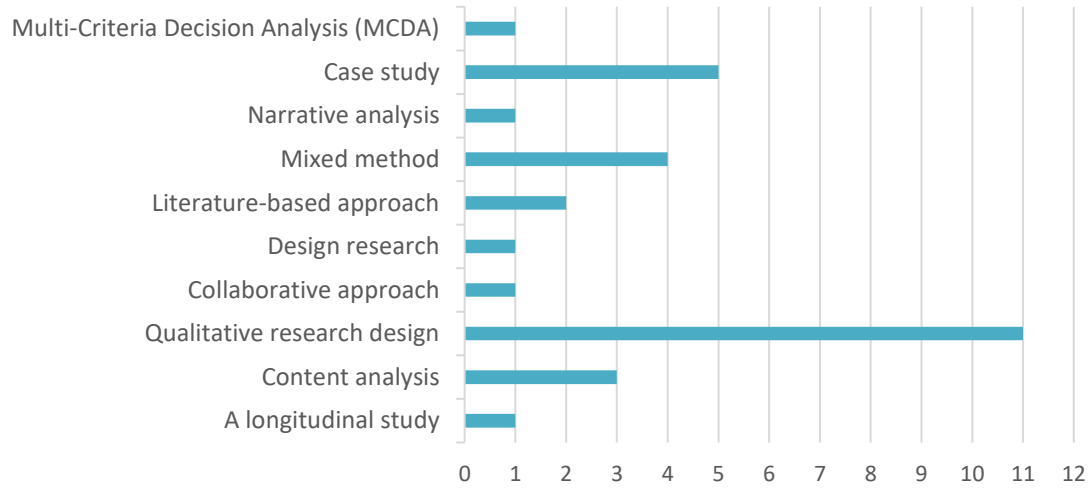

Figure 5. Frequency of research methodologies in the studies

Additional methodologies, such as mixed methods (4 studies) and content analysis (3 studies), provide balanced insights by combining qualitative and quantitative data. These approaches enable researchers to identify patterns and themes while maintaining a broad analytical perspective. Meanwhile, less frequently used methods, such as the literature-based

approach and longitudinal study (2 studies each), contribute to understanding theoretical underpinnings and long-term impacts of sustainability integration in education. Innovative frameworks, including the collaborative approach, design research, and multi-criteria decision analysis (MCDA), though limited in application, highlight advancements in participatory and data-driven educational methodologies. The diversity of these research approaches reflects the complexity of embedding SDGs into educational practices. However, the relatively lower emphasis on quantitative and empirical studies signals an opportunity to expand the evidence base for sustainable education within the mathematics domain.

Contributions to the sustainable development goals (SDGs)

This systematic literature review highlights the crucial role of mathematics education in achieving several Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education). Based on Table 5. studies emphasize mathematical approaches such as problem-solving, logical reasoning, and argumentation, which are vital for addressing sustainability challenges. These skills enable students to engage with complex global issues. Project-based learning and collaborative approaches help bridge the gap between abstract mathematical concepts and real-world sustainability problems. For instance, problem-solving using data analysis, statistical methods, calculus, and function analysis plays a key role in tackling issues like climate action, responsible consumption, and sustainable cities. These mathematical tools help students model and analyze sustainability challenges, equipping them with the skills to find solutions (Albano et al., 2022; Alsina & Mulà, 2019; Boeve-de Pauw et al., 2022; Carmona-Medeiro & Cardeñoso, 2021; Chin et al., 2019; Domínguez-González & Delgado-Martín, 2022).

Mathematical modeling and statistical analysis are essential methods for addressing SDGs related to sustainability and climate action, such as SDGs 12 (Responsible Consumption) and 13 (Climate Action). These techniques enable data analysis, simulations, and predictions to tackle environmental challenges. The use of ICT and flipped learning further enhances sustainability education, especially in the context of SDG 11 (Sustainable Cities). Key mathematical concepts, like percentages, ratios, and optimization, are explored to address environmental and socio-economic issues, reinforcing the role of mathematics in promoting sustainability (Helliwell & Ng, 2022; Helliwell et al., 2023; Jeong & González-Gómez, 2020; Joutsenlahti & Perkkilä, 2024; Kim & Pang, 2022; Lafuente-Lechuga et al., 2020).

Table 5. Contributions to SDGs, mathematical content, and approaches

No	Citation	SDG/ Mathematical Content	Proposal Model /Approach
1	Albano et al. (2022)	SDG 4 Mathematical Problem-Solving and Argumentation in Story Contexts	Dialogic and constructivist approach
2	Alsina and Mulà (2019)	SDG 4 & 13 Logical-Mathematical Reasoning for Sustainability Challenges.	Reflective Learning Model
3	Boeve-de Pauw et al. (2022)	SDG 4 Data analysis of statistic	Project-Based Approach and Systems Thinking for Understanding Sustainability Complexity

No	Citation	SDG/ Mathematical Content	Proposal Model /Approach
4	Carmona-Medeiro and Cardeñoso (2021)	SDG 4 Integrating Logical-Mathematical Learning with Sustainability Values and Collaboration	Project-Based Learning (PBL), Cooperative Learning
5	Chin et al. (2019)	SDG 4 & 12 Calculus Concepts, Volume Optimization, Function Analysis	Blended Learning with Constructivist and Social-Constructivist Approaches: Integrating Face-to-Face and Online Learning
6	Domínguez-González and Delgado-Martín (2022)	SDG 3, 7, 11, 12, 13, 14, 15, 17 Applied Mathematics, Geometry & Trigonometry, Algebra & Functions, Statistics & Finance	Project-Based Learning (PBL) Cooperative Learning
7	Franco Seguí et al. (2024)	SDG 1, 3, 4, 10, 11, 12 Statistics	Mathematics Teacher's Specialized Knowledge (MTSK) Model Mathematics Teaching Itineraries Approach (MTIA)
8	Helliwell and Ng (2022)	SDG 4, 13, 17 Statistical concepts	Inquiry-Based Learning
9	Helliwell et al. (2023)	SDG 4, 13 Mathematical Modeling related to climate change and social justice issues	Critical Mathematics Education (CME)
10	Jeong and González-Gómez (2020)	SDG 4, 11 Sustainability-focused mathematics education and the use of ICT in mathematics teaching	Flipped Learning Model
11	Joutsenlahti and Perkkilä (2024)	SDG 4 Concept of percentage and ratio	Multimodal expressions
12	Kim and Pang (2022)	SDG 1, 2, 3, 4, 5, 6, 7, 8, 11, 12, 13, 15, 16, 17 Numbers and Operations Geometry Measurement Patterns Data and Possibilities	Textbooks
13	Lafuente-Lechuga et al. (2020)	SDG 2, 12 Optimization techniques, Differential equations for socio-economic models	Problem-Based Learning (PBL)
14	le Roux et al. (2022)	SDG 4, 13 Logical-mathematical reasoning and its application to sustainability challenges.	Reflective Learning Model
15	Li and Tsai (2021)	SDG 4 Statistics, Probability, and Mathematical Modeling	Constructivist and Critical Mathematics Education
16	Listiawati et al. (2023)	SDG 4 Measurement, geometry, and application in social contexts	Realistic Mathematics Education (RME)
17	Moreno-Pino et al. (2021)	SDG 4 General mathematics education curriculum content	Green Curriculum model and the EDINSOST sustainability competencies framework
18	Moreno-Pino et al. (2022)	SDG 4 Didactics of Mathematics	Critical Mathematics Education, with a focus on collaborative and reflective learning

No	Citation	SDG/ Mathematical Content	Proposal Model /Approach
19	Naidoo and Reddy (2023)	SDG 4, 13 Statistical and data analysis	Community of Inquiry (CoI), Substitution, Augmentation, Modification, and Redefinition (SAMR)
20	Özdemir (2021)	SDG 4, 6, 12, 13 Data Collection and Presentation, Fractions & Decimals, Number Comparison	Constructivist Approach
21	Özdemir and Kılıç (2023)	SDG 4, 10 Teaching basic math concepts (numbers, addition, basic geometry shapes)	Behaviorist Approach
22	Santamaría-Cárdaba et al. (2021)	SDG 4 Content related to cultural diversity, gender equality, solidarity and responsible consumption	Dialogical and constructivist approach
23	Sari et al. (2024)	SDG 3, 4 Numeracy tasks related to calorie counting, macronutrient and nutrition facts analysis.	Realistic Mathematics Education (RME) Approach
24	Semiz and Baykal (2020)	SDG 4, 6, 7, 9, 11, 12, 15 Percentages, ratio and proportion, geometry, algebra, data analysis, and measurement.	Open-ended approach .
25	Solares-Rojas et al. (2022)	SDG 4, 6, 13 Mathematical modeling	Socio-critical mathematical modelling
26	Su et al. (2022)	SDG 3, 4, 5, 8, 9, 10, 13, 15 Statistics and probability	Interdisciplinary stochastic
27	Suh et al. (2020)	SDG 4, 10 Statistics	Statistical investigation project
28	Summer (2020)	SDG 4 Arithmetic, counting and numerical concepts in the context of sustainable problem solving	Constructivist Approach
29	Tesfamicael and Enge (2024)	SDG 2, 11, 12, 13 Arithmetic, statistics survey, (mean, mode, and median), (algebra, numbers, travel comparisons, percentages, proportionality	Interdisciplinary Approach
30	Vásquez et al. (2021)	SDG 4, 12, 13 Statistics and probability in the context of social and environmental issues	Stochastic Education Approach
31	Vásquez et al. (2022)	SDG 4, 12 Mathematics Curriculum Supporting Understanding of Social, Economic, and Environmental Issues: Numbers, Geometry, Measurement, Algebra, and Statistics. Mathematical Competencies in Data Analysis, Problem Solving, and Understanding Socio-Economic and Environmental Contexts	Interdisciplinary and Transdisciplinary Approaches

Mathematics significantly contributes to achieving the Sustainable Development Goals (SDGs) by addressing key sustainability issues. Integrating mathematical principles with real-

life challenges helps educators connect learning to SDGs such as Quality Education (SDG 4), Clean Water and Sanitation (SDG 6), and Responsible Consumption and Production (SDG 12). Activities like assessing water usage or calculating carbon emissions provide students with insights into the environmental impact of human behavior (Özdemir, 2021; Semiz & Baykal, 2020). In SDG 4, mathematics can incorporate sustainability by exploring resource distribution or analyzing educational inequality. Technology-based tools, such as interactive graphing, also enable students to critically interpret visual data (Franco Seguí et al., 2024). Similarly, in SDG 12, students learn about ratios and statistics to analyze household waste, fostering awareness of responsible consumption (Özdemir, 2021). In SDG 6, students calculate water savings, promoting both mathematical skills and environmental awareness. Mathematics thus fosters social responsibility in addressing global sustainability issues (Semiz & Baykal, 2020; Kim & Pang, 2022). Additionally, games like Jenga, used to teach basic statistics, help students comprehend data related to sustainable community initiatives (Franco Seguí et al., 2024). By integrating these approaches, mathematics education becomes a powerful tool not only for developing numerical skills but also for fostering awareness and social responsibility in addressing global sustainability issues.

Educational levels and subject of the studies

The analysis of selected studies reveals that the integration of sustainability in mathematics education is most prominent in higher education and primary education, each contributing 34% as shown in Figure 6. Higher education focuses on preparing future educators to teach mathematics through a sustainability lens, while primary education introduces basic sustainability concepts. Secondary education represents 29%, addressing complex sustainability challenges using mathematics in real-world contexts. Compulsory education, contributing only 3%, offers introductory sustainability concepts in a simplified form for younger learners. Overall, higher education, primary, and lower secondary education are the primary focus areas for integrating sustainability into mathematics education.

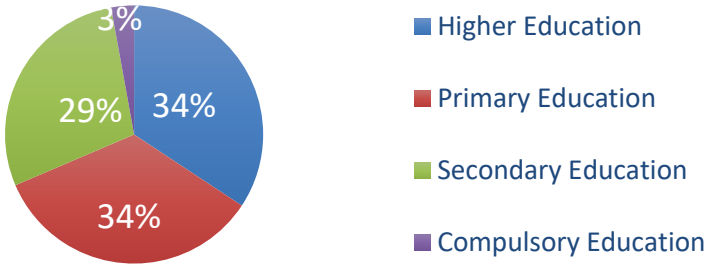

Figure 6. Percentage distribution of studies by educational level

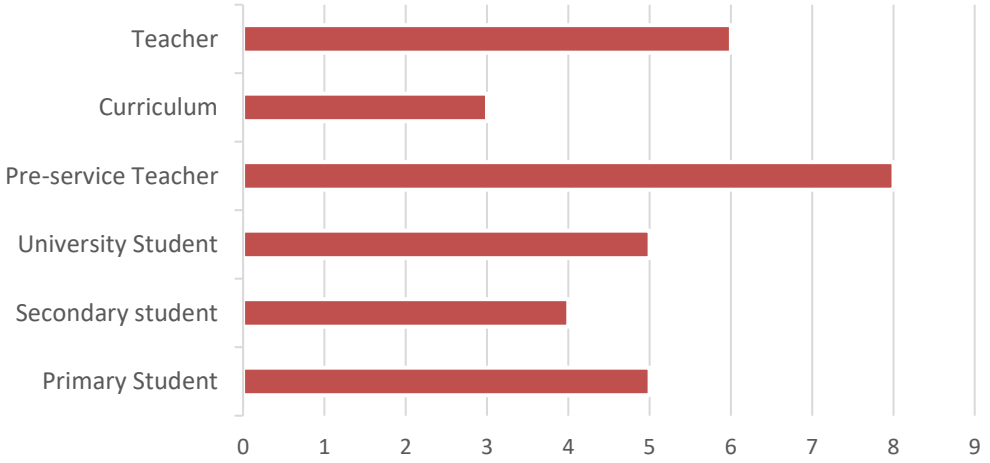

Figure 7. Frequency distribution of studies by subject

Figure 7 illustrates that the reviewed studies emphasize incorporating sustainability within mathematics education at different educational stages, particularly targeting pre-service teachers and students at the primary and secondary levels. Research on pre-service teachers emphasizes developing their competencies to teach sustainability through innovative curricula and pedagogical approaches, preparing them to address real-world challenges (Su et al., 2022; Jeong & González-Gómez, 2020). For primary and secondary students, studies demonstrate the use of mathematics to introduce sustainability concepts, fostering critical thinking and problem-solving skills (Kim & Pang, 2022; Özdemir, 2021). Additionally, professional development for in-service teachers is explored to equip them with the tools to integrate sustainability into their teaching (Boeve-de Pauw et al., 2022; Franco Seguí et al., 2024). Curriculum-focused research emphasizes the need for structural reforms to embed sustainability within interdisciplinary mathematics education (Li & Tsai, 2021; Tesfamicael & Enge, 2024). A smaller number of studies address special education, highlighting inclusive approaches to teaching sustainability to students with diverse needs (Özdemir & Kılıç, 2023). This distribution underscores the interconnected efforts between teacher training, curriculum innovation, and student engagement in promoting sustainability in mathematics education.

Keyword analysis and trends

Based on the cluster visualization generated by VOSviewer in Figure 8, the keyword "sustainability" emerges as the most prominent and central term, reflecting its significant focus in educational research. Figure 8's cluster visualization generated by VOSviewer reveals that "sustainability" is the central and most prominent keyword, reflecting its increasing importance in mathematics education. The yellow cluster, which includes the term "community of inquiry," highlights the value of collaborative and reflective approaches to education. These strategies promote active student engagement, critical thinking, and problem-solving skills essential for addressing sustainability challenges. The visualization underscores the growing focus on reshaping mathematics education to prepare learners for sustainable futures, supported by innovative pedagogical methods.

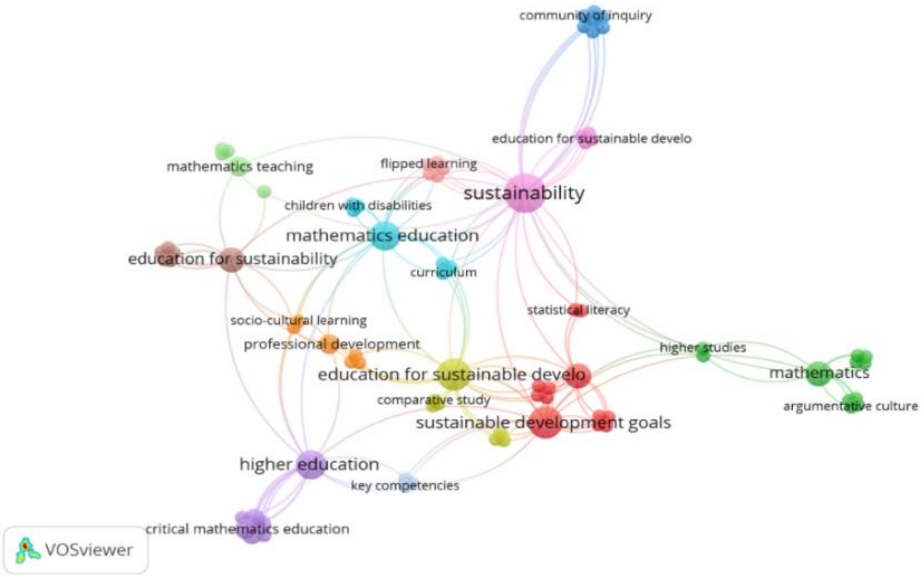

Figure 8. Keyword cluster map of the studies generated using VOSviewer software (Source: Compiled by the authors)

Additionally, the red cluster, which connects "education for sustainable development" and "sustainable development goals," underscores the role of education in achieving global sustainability targets. This alignment demonstrates how mathematics education can contribute to the achievement of SDGs by integrating sustainability themes into the curriculum. Research on linking statistical and probabilistic literacy in primary education textbooks to sustainability themes further illustrates this connection, showing that mathematics can provide the necessary tools for understanding and solving global sustainability challenges (Helliwell et al., 2022; Vásquez et al., 2021).

From a chronological perspective based on Figure 9, terms such as "community of inquiry" and "education for sustainable development" have become more prominent in recent studies (2022–2023), reflecting the increasing focus on pedagogical innovation and how these methods can support sustainable learning. This shift indicates a broader trend toward interdisciplinary approaches and teaching strategies that encourage reflection and collaboration in addressing sustainability. In contrast, terms like "mathematics education" and "higher education" have been widely discussed since 2020–2021 but remain relevant to current research. For example, research on the importance of sustainability competencies in mathematics teacher training highlights the need for educators to be equipped with the necessary skills to integrate sustainability into their teaching. Furthermore, studies on how sustainability concepts can be integrated into mathematics curricula show that practical examples, such as incorporating sustainability issues into mathematics lessons, can foster

students' awareness and understanding of global sustainability challenges (Moreno-Pino et al., 2021; Li & Tsai, 2021).

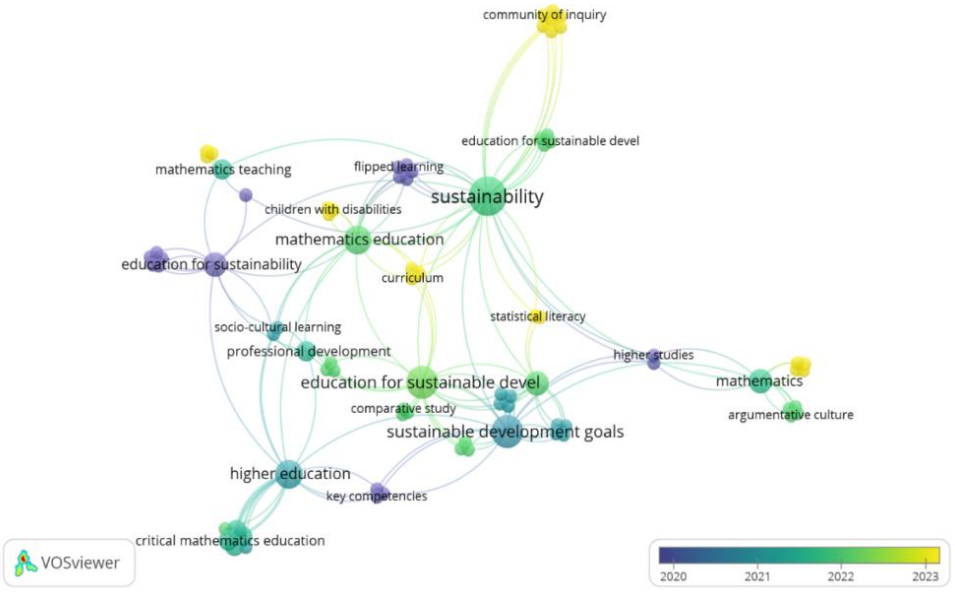

Figure 9. Yearly progression of keywords used in the studies
(Source: Prepared by the authors using VOSviewer software)

Overall, the visualization underscores how sustainability serves as a central theme, bridging various disciplines such as mathematics education, higher education, and technology-driven pedagogical innovations. This indicates that research in this field is dynamically evolving to address global challenges and transform education systems toward sustainability.

Discussion

Incorporating the Sustainable Development Goals (SDGs) into mathematics education is pivotal for developing students who excel not only in mathematical skills but also in the competencies and perspectives needed to contribute to global sustainability. Aligning mathematics education with the SDGs equips students to address real-world challenges such as climate change, inequality, and resource management. By embedding sustainability within the curriculum, educators can encourage the use of mathematical tools to solve problems while fostering critical thinking skills vital for tackling global issues. As highlighted by Helliwell et al. (2022) and Sari et al. (2024), this integration can manifest in various ways, such as embedding real-world contexts into problem-solving exercises or designing numeracy tasks that focus on sustainability-related topics like environmental conservation and nutrition. This approach not only demonstrates the practical relevance of mathematics in addressing urgent contemporary problems but also empowers students to view mathematics as a means to drive positive change (Su et al., 2022).

The systematic review reveals key findings related to the distribution of articles by journal rankings and their geographical spread. Approximately 88% of the studies were published in high-ranking journals (Q1 and Q2), with *Sustainability* contributing the most (26%). These articles focus on competencies for sustainability and reflective learning, highlighting the central role of mathematics education in fostering critical competencies for sustainable development. Geographically, Spain emerges as the leading contributor, producing 26% of the studies, followed by Turkey, Chile, and Indonesia. This distribution underscores regional academic priorities and indicates areas with potential for further exploration.

The research methodologies adopted in the analyzed studies highlight a preference for qualitative approaches (40%), emphasizing contextual exploration of sustainability integration. Mixed methods and experimental designs (30%) complement these efforts, offering balanced insights. However, quantitative and longitudinal studies remain underrepresented, signaling opportunities for future research to strengthen empirical evidence in this domain.

Mathematics education contributes directly to multiple SDGs, primarily SDG 4 (Quality Education), SDG 13 (Climate Action), and SDG 12 (Responsible Consumption and Production). These goals are addressed through mathematical modeling, statistical analysis, and optimization techniques. For instance, linear programming has been applied to optimize food distribution under SDG 2 (Zero Hunger), while data analysis and simulations provide insights into climate change and resource management (Kim & Pang, 2022; Suh et al., 2020).

Educational levels vary significantly, with higher and primary education receiving the most attention (34% each), focusing on teacher training and foundational sustainability concepts. Secondary education represents 29%, where studies explore more complex sustainability challenges. Special and compulsory education, contributing 3%, offer opportunities for inclusive and simplified sustainability education.

Keyword analysis reveals "sustainability" as the most central term, reflecting its significance in educational research. Other trending terms, such as "community of inquiry" and "education for sustainable development," have gained prominence in recent years, highlighting the growing focus on interdisciplinary approaches to teaching sustainability. Chronological trends show a peak in publication activity in 2022, reflecting heightened academic interest during this period, followed by a decline, which may indicate research saturation or shifting priorities.

Teacher professional development is key to effectively integrating SDGs into mathematics education. Training programs must equip educators with the necessary skills to design sustainability-focused curricula and engage students in global challenges (Boeve-de Pauw et al., 2022). Technology also plays an integral role by providing access to real-time data, enabling simulations, and fostering connections between mathematical concepts and sustainability problems (Chin et al., 2019; Naidoo & Reddy, 2023).) further demonstrate the transformative potential of extended reality and machine learning in geometry instruction, showing how immersive technologies can deepen conceptual understanding and increase student engagement in basic education (Cunha et al., 2025).

Project-based learning (PBL) emerges as a transformative approach, encouraging collaboration and critical thinking. This method aligns with SDGs by enabling students to tackle

real-world problems using mathematical tools. Studies have shown that PBL not only strengthens mathematical skills but also fosters personal growth and global responsibility (Domínguez-González & Delgado-Martín, 2022). Similarly, Nguyện et al. (2025) highlight how integrating design thinking into STEM education improves students' problem-solving, creativity, and collaboration approaches that can also enhance mathematics education for sustainability. Additionally, game theory and optimization techniques applied to SDG 12 (Responsible Consumption and Production) demonstrate how mathematical frameworks can address challenges in waste management and resource use (Vásquez et al., 2021).

In conclusion, integrating SDGs into mathematics education offers significant opportunities to develop students' critical thinking, problem-solving, and collaboration skills, all of which are essential for addressing global sustainability challenges. The studies reviewed emphasize the need for teacher professional development, the use of technology, and early exposure to sustainability concepts as key factors for successfully integrating sustainability into the mathematics curriculum. As mathematics education continues to evolve to meet the SDGs, it has the potential to not only enrich students' understanding of mathematical concepts but also empower them to make meaningful contributions to global sustainability efforts, ensuring a more just and sustainable future for all (Tesfamicael & Enge, 2024).

Conclusion

Mathematics education is essential in advancing the Sustainable Development Goals (SDGs) by fostering critical thinking and problem-solving skills. A systematic literature review highlights the growing connection between mathematics and sustainability, with innovative teaching approaches being explored. However, challenges remain, including the limited integration of sustainability in curricula, insufficient teacher training, and disparities in implementation across different education levels. Mathematics provides opportunities to address real-world issues like climate change and resource management through data analysis and mathematical modeling. By embedding sustainability into mathematics education, students can develop a deeper understanding of global challenges and contribute to meaningful solutions. Overcoming traditional teaching barriers and resistance to change is crucial for effective implementation. Therefore, collaboration among educators, researchers, and policymakers is necessary to integrate sustainability into education and prepare students to become problem-solvers in an evolving world.

This study is limited by its reliance on peer-reviewed articles published between 2019 and 2024, which may exclude valuable insights from grey literature or non-English publications. In addition, the focus on qualitative content analysis means that some contextual variations across countries and education systems may not be fully captured. Future research should consider broader data sources, including teacher practices, student perceptions, and longitudinal impacts of ESD integration in mathematics. The implications of this review suggest that curriculum designers, education policymakers, and teacher training institutions must prioritize interdisciplinary approaches and provide sustained support for educators. This

effort will ensure that mathematics education does not merely serve academic purposes but becomes a transformative tool for sustainability.

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Conflicts of Interest

The authors declare no conflict of interest regarding the publication of this manuscript.

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Author Contributions

Sri Intan Lina: Responsible for conceptualization, drafting the original manuscript, editing, visualization, reviewing, conducting formal analysis, and developing the methodology; **Rahmah Johar:** Oversight and validation**; Anwar:** Supervision and validation.

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