Integration of Education for Sustainable Development in Mathematics Education: A Scoping Review

Elizar Elizar
Universitas Syiah Kuala
elizar@usk.ac.id

Dwi Fadhiliani
Universitas Syiah Kuala
dwifadhiliani@usk.ac.id

Erni Maidiyah
Universitas Syiah Kuala
ernimaidiyah@usk.ac.id

This review explores research on integrating Education for Sustainable Development (ESD) into mathematics education. Significant findings indicate that mathematics education can enhance ESD competencies. However, challenges persist, including limited teacher preparation, curriculum constraints, and tensions between mathematical rigour and sustainability contexts. The review emphasises four key instructional methods: problem-based learning on sustainability issues, mathematical modelling for real-world sustainability problems, STEM education, and Place-Based Education (PBE).

Introduction

The integration of Education for Sustainable Development (ESD) into formal education systems has seen significant growth after the United Nations Decade of Education for Sustainable Development (2005-2014) and the later adoption of the Sustainable Development Goals (SDGs) in 2015. ESD aims to equip students with the knowledge, skills, values, and attitudes necessary to address complex sustainability challenges, including climate change, resource depletion, social inequality, and environmental degradation (Vorhölter et al., 2025). ESD has been widely implemented in science and social studies; however, its integration into mathematics education remains relatively underexplored (Li et al., 2021; Su et al., 2023).

Mathematics education has a unique position in the ESD landscape. On one hand, mathematical literacy is essential for understanding and addressing sustainability challenges, from analysing climate data to modelling resource consumption patterns (Tesfamicael et al., 2024). On the other hand, the abstract nature of mathematics and its traditional emphasis on decontextualised problem-solving have created barriers to meaningful ESD integration (Alsina et al., 2023). Recent scholarship has begun to address this gap, exploring how mathematics education can contribute to sustainability goals while maintaining mathematical rigour and coherence (Semiz et al., 2020; Hopkinson et al., 2010).

The rationale for integrating ESD in mathematics education rests on several foundations. First, mathematics provides powerful tools for analysing, modelling, and solving real-world sustainability problems (Vásquez et al., 2023a). Second, contextualised mathematics instruction grounded in sustainability themes can enhance student engagement and demonstrate the relevance of mathematical concepts (Wiegand & Borromeo Ferri, 2023). Third, mathematics education can contribute to the development of critical sustainability competencies, including systems thinking, critical analysis, and collaborative problem-solving (Vásquez et al., 2022).

This scoping review synthesises current research on ESD integration in mathematics education, examining pedagogical approaches, curriculum strategies, implementation challenges, and learning outcomes. The review addresses the following research questions: (1) What pedagogical approaches are employed to integrate ESD in mathematics education? (2) What challenges and barriers affect implementation? (3) What learning outcomes and effectiveness evidence exist for ESD-mathematics integration?

(2026). In N. Berger, M. Thompson, J. Ley & C. Wilsmore (Eds.), *Beyond boundaries: Strengthening futures in mathematics education. Proceedings of the 48th annual conference of the Mathematics Education Research Group of Australasia, Sydney* (pp. 130–137). MERGA.

Methodology

This review drew from a comprehensive search of scholarly articles on ESD integration in mathematics education conducted in SciSpace and Google Scholar databases. The initial search resulted in 220 papers (200 from SciSpace and 20 from Google Scholar). After removing duplicates and applying inclusion criteria, 77 peer-reviewed journal articles were identified. Papers were filtered to include only journal articles from reputable international publications and sorted by relevance to the research questions.

The review focuses on the top 21 most relevant papers, which were analysed to identify key themes, pedagogical approaches, implementation challenges, and reported outcomes. Data extraction focused on study context, theoretical frameworks, pedagogical methods, curriculum integration strategies, reported challenges, and learning outcomes. Thematic analysis was employed to synthesise findings across studies and identify patterns, convergences, and gaps in the literature.

Theoretical Foundations and Frameworks

The integration of ESD into mathematics education is grounded in several theoretical frameworks. The UNESCO framework for ESD competencies provides the foundation, emphasising systems thinking, anticipatory thinking, normative competence, strategic competence, collaboration, critical thinking, self-awareness, and integrated problem-solving (Vorhölter et al., 2025). These competencies align with mathematical practices, particularly in modelling, problem-solving, and reasoning.

Mathematical modelling serves as a central theoretical bridge between mathematics and sustainability. Modelling involves formulating, solving, validating, and communicating mathematical representations of real-world phenomena, making it particularly suitable for addressing complex sustainability issues (Wiegand & Borromeo Ferri, 2023; Bulut & Borromeo Ferri, 2025). The modelling cycle, which transitions between real-world contexts and mathematical representations, incorporates systems thinking and critical analysis, the core of ESD.

Place-Based Education (PBE) theory provides another important framework, emphasising connections between mathematical learning and local environmental and social contexts (Teise, 2025). This approach grounds abstract mathematical concepts in students' lived experiences and local sustainability challenges, enhancing relevance and engagement while developing place-based knowledge and action competence.

Science, Technology, Engineering, Arts, and Mathematics (STEAM) integration frameworks offer interdisciplinary approaches to ESD-mathematics integration (Alsina et al., 2023). These frameworks emphasise connections across disciplines, authentic problem-solving, and creative thinking, aligning with the holistic, interdisciplinary nature of sustainability challenges.

Key Themes and Findings

Pedagogical Approaches and Practical Implications

Efforts to integrate ESD into mathematics education have led researchers to explore a range of pedagogical approaches. Rather than identifying a single preferred method, the literature suggests that sustainability can be meaningfully incorporated into mathematics classrooms through various forms of contextualised, inquiry-oriented learning. Across these approaches, mathematics is positioned not only as a set of abstract procedures but also as a tool for understanding and responding to complex environmental and social issues. Importantly, the studies reviewed indicate that sustainability contexts can enrich mathematical learning when

they are authentically connected to real-world problems rather than added superficially to routine exercises.

One of the most frequently discussed approaches is the use of sustainability-related contexts in mathematical problem-solving and inquiry activities. In these learning environments, students engage with issues such as climate change, resource consumption, waste production, or social inequality while applying mathematical concepts and reasoning. Research suggests that these contexts can make mathematical tasks feel more meaningful and relevant to students while still maintaining mathematical rigour (Domínguez-González & Delgado-Martín, 2022; Li et al., 2021). However, scholars caution that simply inserting environmental terminology into traditional word problems is insufficient for meaningful ESD integration. Instead, tasks need to involve genuine sustainability challenges that encourage critical thinking, interpretation, and discussion. For teachers, this finding suggests that effective ESD integration does not necessarily require a complete curriculum redesign, but rather thoughtful adaptation of existing mathematical topics using authentic sustainability contexts.

Mathematical modelling has received particular attention in the literature as a powerful means of connecting mathematics and sustainability. Modelling activities typically require students to represent real-world phenomena mathematically, test assumptions, interpret results, and evaluate possible solutions. Sustainability-related issues, such as population growth, energy consumption, transportation systems, and carbon emissions, provide particularly rich contexts for this work. Studies indicate that modelling activities can support not only mathematical understanding but also competencies commonly associated with ESD, including systems thinking, critical analysis, and decision making (Wiegand & Borromeo Ferri, 2023; Bulut & Borromeo Ferri, 2025; Vorhölter et al., 2025). One example presented by Wiegand and Borromeo Ferri (2023) asked students to analyse the energy consumption of aluminium production in Brazil and Germany and to evaluate how relocating production might contribute to sustainable development. Such tasks demonstrate how mathematical modelling can encourage students to consider environmental, economic, and social dimensions simultaneously. The literature also suggests that teachers can begin with accessible and locally relevant datasets, such as community waste statistics, water usage data, or energy consumption records, to make modelling activities more manageable and meaningful for students.

Another approach highlighted in the literature involves linking mathematics lessons explicitly to the SDGs. Researchers describe SDG-linked problem design as an accessible entry point for teachers new to ESD integration, as it allows sustainability themes to be embedded within existing curriculum topics (Domínguez-González & Delgado-Martín, 2022; Lestari et al., 2024). For example, percentage calculations can be connected to discussions about gender pay gaps (SDG 5), while exponential functions can be used to model population growth, plastic accumulation, or resource depletion (SDG 12). Studies suggest that this approach can increase student motivation because mathematical concepts are connected to issues students recognise from everyday life and global discussions. At the same time, the literature emphasises the importance of maintaining mathematical depth so that sustainability contexts support rather than overshadow conceptual understanding.

Interdisciplinary learning environments provide another pathway for integrating sustainability into mathematics education. Because sustainability challenges are inherently complex and cross-disciplinary, projects combining mathematics with science, technology, or engineering appear frequently in the literature. Examples include analysing environmental data, designing technologies for monitoring ecosystems, or investigating renewable energy systems. Research suggests that these interdisciplinary experiences can strengthen students' awareness of sustainability issues while also deepening conceptual understanding of mathematics (Gerretson et al., 2008; Hopkinson & James, 2010). However, scholars also note that interdisciplinary work requires careful planning; otherwise, mathematics risks being reduced to

a supporting tool rather than remaining a subject of inquiry in its own right. This highlights the importance of designing tasks where mathematical reasoning remains central to the investigation.

A somewhat different perspective emerges from research on PBE. Here, the emphasis shifts from global sustainability concerns to the local communities and environments in which students live. Mathematical investigations may involve analysing local biodiversity data, measuring patterns of waste production, examining water usage, or designing sustainable community spaces. Studies suggest that these locally grounded approaches can increase student engagement by helping students see how mathematics connects to their everyday experiences and communities (Teise, 2025; Kadji-Beltran et al., 2017). PBE also appears to encourage civic awareness and participation by positioning students as active contributors to understanding local sustainability challenges.

Beyond classroom practice, the literature also highlights several institutional and systemic factors that influence the successful integration of ESD into mathematics education. Teacher professional development emerges as one of the most important conditions for effective implementation, particularly programs that combine sustainability knowledge, collaborative lesson design, classroom experimentation, and opportunities for reflection on balancing mathematical rigour with sustainability contexts (Su et al., 2023; Alsina & Silva-Hormazábal, 2023; Olawale et al., 2025). Similarly, pre-service teacher education programs are encouraged to embed ESD principles directly within mathematics methods courses rather than treating sustainability as a separate topic (Bulut & Borromeo Ferri, 2025). The literature also points to the need for high-quality curriculum resources, as existing textbooks often include sustainability only superficially (Kim and Pang 2022). At the systemic level, curriculum frameworks such as Norway's LK20 curriculum demonstrate how sustainability can be embedded as a cross-curricular theme that explicitly includes mathematics (Tesfamicael & Enge, 2024), while initiatives such as the CoDesignS ESD Framework provide models for integration within university mathematics teacher education programs (Ahmad et al., 2023).

Taken together, the reviewed studies illustrate that there is no single pathway for integrating ESD into mathematics education. Instead, the literature reflects an ongoing effort to identify pedagogical practices that allow students to develop mathematical understanding while critically engaging with authentic sustainability issues. At the same time, the findings suggest that successful implementation depends not only on classroom strategies but also on broader institutional support, teacher preparation, curriculum resources, and policy alignment.

Curriculum Integration Strategies

Researchers have proposed several ways of incorporating ESD into mathematics curricula. These approaches vary widely, from relatively small adjustments to existing lessons to more comprehensive curriculum changes. However, studies of mathematics textbooks suggest that sustainability is still only marginally represented in many curricular materials. Analyses across countries show that references to sustainability are infrequent and unevenly distributed (Kim and Pang 2022).

Even when sustainability contexts are included, they are often used simply as the setting for routine mathematical problems rather than as opportunities for students to engage more deeply with sustainability issues.

Some education systems have attempted to address this gap through curriculum reform. For example, Norway's recent curriculum explicitly identifies sustainability as a cross-cutting theme that should be integrated across subjects, including mathematics (Tesfamicael et al., 2024). Such policy frameworks can provide important structural support for integrating ESD. Nevertheless, the extent to which sustainability is actually incorporated into classroom practice depends on several factors, including teachers' familiarity with ESD, the availability of

appropriate teaching resources, and the alignment between curriculum goals and assessment practices.

In the literature, several practical strategies for curriculum integration have been discussed. One common approach is to introduce sustainability-related examples into existing mathematical topics so that students can see how familiar concepts apply to real-world issues. Other initiatives develop dedicated instructional units that focus more explicitly on the use of mathematics to analyse sustainability challenges. Project-based learning has also been explored, allowing students to investigate sustainability problems over extended periods. At the most ambitious level, some scholars advocate for broader curriculum redesign in which sustainability becomes a central theme throughout the mathematics program (Ahmad et al., 2023). Each of these approaches requires different levels of effort and support, and they vary in how deeply sustainability becomes embedded in students' mathematical learning.

Implementation Challenges

Despite growing interest in integrating ESD and mathematics, significant challenges impede widespread implementation. Teacher preparation emerges as the most frequently cited barrier. Many mathematics teachers lack training in ESD principles, pedagogical approaches for integration, and confidence in addressing sustainability topics (Su et al., 2023; Olawale et al., 2025). Teachers report uncertainty about how to maintain mathematical rigour while incorporating sustainability contexts and concerns about their own knowledge of sustainability issues.

Curriculum constraints present another major challenge. Crowded curricula, standardised testing pressures, and traditional mathematical scope and sequence create barriers to incorporating sustainability contexts and extended modelling activities (Semiz et al., 2020). Teachers report tension between covering required mathematical content and dedicating time to sustainability-focused activities, particularly when assessments do not value ESD competencies.

Conceptual tensions between mathematics and sustainability create additional challenges. Some educators question whether sustainability contexts compromise mathematical abstraction and generalisation, while others worry that superficial integration may trivialise either mathematics or sustainability (Meyer, 2026). Balancing mathematical learning goals with ESD objectives requires careful pedagogical design and ongoing reflection.

Resource limitations, including a lack of appropriate teaching materials, assessment tools, and professional development opportunities, further constrain implementation (Vásquez et al., 2023b). Many teachers lack access to high-quality, curriculum-aligned resources that authentically integrate mathematics and sustainability.

Learning Outcomes and Effectiveness

Research on learning outcomes from ESD-mathematics integration has yielded promising yet mixed results. Studies report that well-designed integration can enhance both mathematical understanding and sustainability competencies without compromising either domain (Wiegand & Borromeo Ferri, 2023). Students engaged in sustainability-focused mathematical modelling demonstrate improved systems thinking, critical analysis, and the ability to work with complex, ill-defined problems.

Affective outcomes include increased student engagement, enhanced perceptions of the relevance of mathematics, and greater awareness of sustainability issues (Domínguez-González & Delgado-Martín, 2022; Li et al., 2021). Students report finding sustainability contexts more meaningful than traditional textbook problems and appreciate opportunities to apply mathematics to real-world issues they care about.

However, outcomes vary significantly based on implementation quality, teacher expertise, and pedagogical approach. Superficial integration that merely changes problem contexts without substantive engagement with sustainability issues has a limited impact on both mathematical and sustainability learning (Kim and Pang 2022). Effective integration requires sustained engagement, authentic tasks, and explicit attention to both mathematical and ESD learning goals.

Assessment of ESD competencies in mathematics contexts remains underdeveloped. Few studies employ validated instruments to measure sustainability competencies, and most rely on self-report measures or qualitative analyses of student work (Holst et al., 2024). The development of robust assessment frameworks that capture both mathematical and ESD learning is an important research need.

Discussion

The synthesis of the literature reveals that mathematics education has significant potential to contribute to ESD goals, but realising this potential requires addressing substantial pedagogical, curricular, and systemic challenges. The field has moved beyond questioning whether mathematics should engage with sustainability toward exploring how to do so effectively while maintaining mathematical integrity and achieving meaningful sustainability learning.

Several key insights emerge from the review. First, effective ESD-mathematics integration requires more than simply changing problem contexts; it demands pedagogical approaches that engage students in authentic mathematical practices applied to genuine sustainability challenges. Mathematical modelling emerges as particularly promising because it naturally incorporates systems thinking, critical analysis, and decision-making, which are central to both mathematics and ESD.

Second, teacher education represents a critical leverage point for advancing ESD-mathematics integration. Pre-service and in-service teacher education must address both content knowledge (understanding of sustainability issues and ESD principles) and pedagogical content knowledge (how to design and implement effective integration) (Su et al., 2023; Alsina et al., 2023). Teachers need opportunities to experience ESD-mathematics integration as learners, develop appropriate pedagogical approaches, and reflect on tensions and challenges.

Third, curriculum and assessment systems must evolve to support and value ESD-mathematics integration. When standardised assessments focus exclusively on decontextualised mathematical procedures, teachers face disincentives for investing time in sustainability-focused activities. Curriculum frameworks that explicitly mandate and support ESD integration, coupled with assessment systems that value sustainability competencies, create enabling conditions for implementation (Tesfamicael et al., 2024).

Fourth, the field needs more rigorous research on learning outcomes and effectiveness. While existing studies provide promising evidence, many rely on small samples, short interventions, and limited outcome measures. Longitudinal studies examining sustained impacts on both mathematical achievement and sustainability competencies, using validated assessment instruments, strengthen the evidence base.

Finally, attention to equity and justice dimensions of ESD-mathematics integration remains limited in the literature. Sustainability challenges disproportionately affect marginalised communities, and mathematics education can either reproduce or challenge these inequities. Future work should explicitly address how ESD-mathematics integration can promote social justice and ensure that all students develop the mathematical and sustainability competencies needed for informed citizenship.

Conclusion and Future Directions

This comprehensive literature review demonstrates that integrating ESD in mathematics education represents both a significant opportunity and a complex challenge. Mathematics provides powerful tools for understanding and addressing sustainability issues, and appropriately designed instruction can develop both mathematical competencies and critical sustainability competencies. However, effective integration requires substantial shifts in pedagogy, curriculum, teacher education, and assessment systems.

Future research should prioritise several directions. First, developing and validating assessment frameworks that capture both mathematical and ESD learning outcomes would strengthen the field's ability to evaluate effectiveness. Second, longitudinal studies examining the sustained impacts of ESD-mathematics integration on student learning, attitudes, and behaviours would provide crucial evidence. Third, research on teacher learning and professional development for ESD-mathematics integration would inform efforts to build teacher capacity. Fourth, an investigation of how ESD-mathematics integration can promote equity and social justice would address critical gaps in current literature.

For practice, the review suggests several recommendations. Teacher education programs should incorporate ESD principles and pedagogical approaches for integration into mathematics methods courses. Curriculum developers should create high-quality resources that authentically integrate mathematics and sustainability while maintaining mathematical rigour. School systems should provide professional development, collaborative planning time, and supportive assessment policies that enable teachers to implement ESD-mathematics integration effectively. Policymakers should ensure that curriculum frameworks and standards explicitly support and value ESD integration across all subjects, including mathematics.

As sustainability challenges are unprecedented, education systems must evolve to prepare students for informed, responsible citizenship. Mathematics education, with its emphasis on logical reasoning, quantitative analysis, and problem-solving, has essential contributions to make. By thoughtfully integrating ESD principles and practices, mathematics education can help develop the next generation of citizens equipped with both mathematical competencies and sustainability consciousness needed to build a more just and sustainable world.

References

Ahmad, N., Zainuddin, N., Wahab, N. A., & Rahim, M. B. (2023). CoDesignS Education for Sustainable Development: A framework for embedding education for sustainable development in curriculum design. *Sustainability*, *15*(23), 16460. https://doi.org/10.3390/su152316460

Alsina, Á., Batllori, R., Falgàs, M., & Vidal, I. (2023). Promoting mathematics teacher education for sustainability through a STEAM approach. *Avances de Investigación en Educación Matemática*, *23*, 73-95. https://doi.org/10.35763/aiem23.5402

Bulut, N., & Borromeo Ferri, R. (2025). Bridging mathematical modelling and education for sustainable development in pre-service primary teacher education. Education Sciences, 15(2), 248. https://doi.org/10.3390/educsci15020248

Domínguez-González, R., & Delgado-Martín, L. (2022). Arousing early strategic thinking about SDGs with real mathematics problems. Mathematics, 10(9), 1446. https://doi.org/10.3390/math10091446.

Gerretson, H., Howes, E., Campbell, S., & Thompson, D. (2008). Interdisciplinary mathematics and science education through robotics technology: its potential for education for sustainable development (a case study from the USA). Journal of Teacher Education for Sustainability, 10(1), 32. https://doi.org/10.2478/V10099-009-0023-4

Holst, J., Singer-Brodowski, M., Brock, A., & De Haan, G. (2024). Monitoring SDG 4.7: Assessing Education for Sustainable Development in policies, curricula, training of educators, and student assessment (input-indicator). Sustainable Development, 32(4), 3908–3923.

Hopkinson, P., & James, P. (2010). Practical pedagogy for embedding ESD in science, technology, engineering and mathematics curricula. *International Journal of Sustainability in Higher Education*, 11(4), 365–379. https://doi.org/10.1108/14676371011077586

Kadji-Beltran, C., Christodoulou, N., Zachariou, A., Lindemann-Matthies, P., Barker, S., & Kadis, C. (2017). An ESD pathway to quality education in the Cyprus primary education context. Environmental Education Research, 23(7), 1015–1031.

Kim, J., & Pang, J. (2022). *An Analysis of Sustainable Activities in Japanese, Korean, and Singaporean Elementary Mathematics Textbooks*. *Eurasia Journal of Mathematics, Science and Technology Education, 18*(2), em2080. https://doi.org/10.29333/ejmste/11651

Li, M., Lam, C. C., & Chik, P. M. (2021). Education for sustainable development in mathematics education: What could it look like? *International Journal of Mathematical Education in Science and Technology*, *52*(7), 1109-1119. https://doi.org/10.1080/0020739X.2021.1941361

Meyer, M. (2026). Sustainable Development in Mathematics versus Mathematics in Sustainable Development: Elaboration of Challenges and Tensions in Curriculum Design and Implementation. Research in Integrated STEM Education, 1(aop), 1–23.

Olawale, B. E., Hendricks, W., & Saddiq, K. (2025). Education for sustainable development and its implications for the preparation of pre-service mathematics teachers. In B. E. Olawale (Ed.), Building the Foundations: Effective Approaches in Mathematics Teacher Preparation (pp. 88–104). ERRCD Forum.

Semiz, K., Tican, C., & Aksu, Z. (2020). Middle school pre-service mathematics teachers' opinions related to mathematics education for sustainability. *Eurasian Journal of Educational Research*, *20*(89), 175–200. https://doi.org/10.14689/EJER.2020.89.6

Su, Y., Liang, S., & Xie, N. (2023). Sustainable development education for training and service teachers teaching mathematics: A systematic review. *Sustainability*, *15*(10), 8435. https://doi.org/10.3390/su15108435

Teise, K. L. (2025). Place-based mathematics education: An education for sustainable development pedagogy to enhance mathematics teacher training. In B. E. Olawale (Ed.), Building the Foundations: Effective Approaches in Mathematics Teacher Preparation (pp. 72–87). ERRCD Forum.

Tesfamicael, S. A., & Enge, O. (2024). Revitalising Sustainability in Mathematics Education: The Case of the New Norwegian Curriculum. Education Sciences, 14(2), 174. https://doi.org/10.3390/educsci14020174

Vásquez, C., Alsina, Á., Pincheira, N., Gea, M. M., & Chandía, E. (2022). What challenges does the 21st century impose on the knowledge of primary school teachers who teach mathematics? An analysis from a Latin American perspective. *Mathematics*, *10*(3), 391. https://doi.org/10.3390/math10030391

Vásquez, C., García-Alonso, I., Seckel, M. J., & Alsina, Á. (2023a). Integrating sustainability in mathematics education and statistics education: A systematic review. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(12), em2373. https://doi.org/10.29333/ejmste/13809

Vásquez, C., Ruz, F., Martínez, M. V., & Alsina, Á. (2023b). Connecting statistics education and sustainability: Beliefs of primary education teachers. *Avances de Investigación en Educación Matemática*, *23*, 97-118. https://doi.org/10.35763/aiem23.5415

Vorhölter, K., Krüger, A., & Wendt, L. (2025). Education for sustainable development in mathematics classrooms. *Environmental Education Research*. https://doi.org/10.1080/13504622.2025.2565461

Wiegand, S., & Borromeo Ferri, R. (2023). Promoting pre-service teachers' professionalism in STEAM education and education for sustainable development through mathematical modelling activities. *ZDM–Mathematics Education*, 55(7), 1269–1282. https://doi.org/10.1007/s11858-023-01500-8