Mandalika Mathematics and Education Journal
Volume 7 Nomor 4, Desember 2025
e-ISSN 2715-1190| |p-ISSN 2715-8292
DOI: http://dx.doi.org/10.29303/jm.v7i1.9929

Eco-green mathematics and artificial intelligence: a systematic review on sustainable mathematical literacy

Sunismi[1], Abdul Halim Fathani[1], Yayan Eryk Setiawan[1], Gusti Firda Khairunnisa[1*]

[1] *Pendidikan Matematika, FKIP, Universitas Islam Malang, Malang*

firdakhairunnisa123@unisma.ac.id

Abstract
The advancement *of eco-green mathematics* and *artificial intelligence (AI)* in education provides opportunities to improve sustainable mathematical literacy and support innovative learning practices. This study aims to provide a comprehensive overview of research trends, roles, and best practices in the integration of AI and *eco-green mathematics* to strengthen sustainability-oriented mathematical literacy. This study uses *the systematic literature review (SLR)* method with strict guidelines, following *the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).* A literature search was conducted through the Scopus database for articles published between 2019 and 2025, resulting in 34 studies relevant to this topic. The results show that AI in mathematics education is applied through *intelligent tutoring systems*, adaptive learning platforms, and machine learning-based tools, while *eco-green mathematics* emphasizes mathematical modeling to answer ecological and social sustainability challenges. Most of the research was conducted in Europe, Asia, and the United States, with a predominance of conceptual, bibliometric, and mixed-approach studies. The analysis highlights key themes such as trends and concepts, the role of AI, best practices, challenges and opportunities, and future research directions related to sustainable mathematical literacy. Therefore, the synergy of smart technology, green curriculum, and pedagogical innovation will be the key to building *sustainable mathematical literacy* in the digital era.

Keywords: artificial intelligence; eco-green mathematics; sustainable mathematical literacy; PRISMA; systematic literature review

Abstrak
Kemajuan *eco-green mathematics* dan *artificial intelligence (AI)* dalam pendidikan memberikan peluang untuk meningkatkan literasi matematis berkelanjutan serta mendukung praktik pembelajaran yang inovatif. Kajian ini bertujuan untuk memberikan tinjauan komprehensif mengenai tren penelitian, peran, dan praktik terbaik dalam integrasi AI dan *eco-green mathematics* untuk memperkuat literasi matematis yang berorientasi pada keberlanjutan. Penelitian ini menggunakan metode *systematic literature review (SLR)* dengan pedoman yang ketat, mengikuti *Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA).* Pencarian literatur dilakukan melalui basis data Scopus untuk artikel yang diterbitkan antara 2019 hingga 2025, menghasilkan 34 studi yang relevan dengan topik ini. Hasil kajian menunjukkan bahwa AI dalam pendidikan matematika diterapkan melalui *intelligent tutoring systems*, platform pembelajaran adaptif, dan alat berbasis *machine learning*, sementara *eco-green mathematics* menekankan pemodelan matematika untuk menjawab tantangan keberlanjutan ekologi dan sosial. Sebagian besar penelitian dilakukan di Eropa, Asia, dan Amerika Serikat,

dengan dominasi studi konseptual, bibliometrik, dan pendekatan campuran. Analisis ini menyoroti tema utama seperti tren dan konsep, peran AI, praktik terbaik, tantangan dan peluang, serta arah penelitian masa depan terkait literasi matematis berkelanjutan. Oleh karena itu, sinergi antara AI, *ecogreen,* dan inovasi pedagogis akan menjadi kunci dalam membangun literasi matematis yang berkelanjutan di era digital.

Kata Kunci: *artificial intelligence*; *eco-green mathematics*; literasi matematis berkelanjutan; PRISMA; *systematic literature review*

1. Introduction

1.1 Research Background

The development of science and technology in the last two decades has encouraged the emergence of new approaches in education, particularly mathematics education, which emphasizes environmental sustainability and the use of smart technologies. The concept *of eco-green mathematics* is becoming increasingly relevant because it combines mathematical understanding with environmental awareness, which aims to solve global problems such as climate change, energy management, and resource conservation (Mayasari et al., 2019; Lafuente-Lechuga et al., 2020). In addition, sustainable mathematical literacy is seen as an important skill in preparing the younger generation to face the challenges of the 21st century (Alsina, 2023; García-Alonso et al., 2023).
Eco-green mathematics emphasizes real-context-based mathematics learning that fosters students' awareness of environmental issues through the application of mathematical concepts. This approach is in line with UNESCO's vision of continuing education, which is to integrate mathematical literacy with social, economic, and ecological dimensions (Kim & Pang, 2022; Bulut & Borromeo Ferri, 2025). Several studies have shown that associating mathematical concepts with environmental problems can improve students' learning motivation, critical thinking skills, and problem-solving abilities (Sunzuma & Luneta, 2023; Lucas & Paulo, 2024).

On the other hand, the development of *artificial intelligence* (AI) opens up great opportunities to support more effective, adaptive, and environmentally friendly mathematics learning. The concept *of green AI,* which emphasizes energy efficiency and reducing the carbon footprint of technology, is increasingly being studied in the context of education (Bolón-Canedo et al., 2024; Emon et al., 2024). AI can assist teachers in designing personalized learning, providing data-driven learning analytics, and facilitating the use of resource-efficient interactive media (Ahmad et al., 2025; Darwish et al., 2025). This integration supports the idea that technology serves not only as a tool, but also as a driver of sustainable education.

Sustainable *mathematical literacy* requires students to not only understand mathematical concepts, but also to be able to apply them in a global context related to sustainability. According to García-Alonso et al. (2023) affirms that sustainability-oriented mathematical literacy competencies include systemic thinking skills,

collaboration, and cross-disciplinary problem-solving. Mathematical modeling, for example, can be used to analyze environmental data or predict climate change trends (H.-C. Li, 2025; Lucas & Paul, 2024). The integration of AI in this context strengthens students' ability to understand complex data and develop evidence-based solutions (Opesemowo & Adewuyi, 2024; Son et al., 2025).

Several studies have shown a positive relationship between the application of AI technology, mathematical learning, and the development of sustainability awareness. For example, Song et al., (2025) found that the use of AI-based tools in math classrooms is able to improve students' engagement and their digital literacy, which is an important part of 21st-century literacy. In addition, *the AI-supported approach to eco-green mathematics* provides opportunities to develop project-based learning and contextual problem-solving (Ngoveni, 2025; Stefanova & Georgiev, 2024). Studies by Alsina & Vásquez (2024) also show that teacher training in combining green technology and sustainable mathematics improves pedagogic competencies relevant to future education.

Although the potential for integrating *eco-green mathematics* and AI is huge, there are still various challenges, such as the limited understanding of teachers, the availability of environmentally friendly technology infrastructure, and the need for a curriculum that supports sustainable literacy (Karaarslan Semiz & Isler Baykal, 2020; Wijaya et al., 2024). In addition, the ethical aspects of the use of AI must also be considered, such as the risk of technological dependence and its impact on students' creativity (Opesemowo & Ndlovu, 2024; Yıldız & Körpeoğlu, 2025). Therefore, an in-depth study is needed on how the integration of these two approaches can be optimized in the context of modern mathematics learning.

Based on this background, this article aims to conduct *a systematic review* of the role of *eco-green mathematics* and *artificial intelligence* in building *sustainable mathematical literacy*. In particular, this article focuses on (1) Identifying trends, concepts, and developments in research related to *eco-green mathematics* in support of sustainable mathematical literacy. (2) Analyze the role and contribution of *artificial intelligence (AI)* in sustainability-oriented mathematics learning. (3) Review models, strategies, and best practices in the integration of *eco-green mathematics* and AI to improve sustainable mathematical literacy. (4) Uncover challenges, opportunities, and research gaps related to the implementation of AI and *eco-green mathematics* in the context of mathematics education. (5) Provide recommendations for future research directions relevant to the development of sustainable technology-based mathematical literacy and environmentally friendly approaches.

1.2 Research Questions

1. What are the current trends and research directions related to *eco-green mathematics* in supporting *sustainable mathematical literacy*?

2. What is the role and contribution of AI in mathematics learning innovations to build sustainable mathematical literacy?
3. What models, approaches, or best practices have been identified of the integration of *eco-green mathematics* and AI in mathematical literacy?
4. What challenges and opportunities have been found from the literature related to the application of AI and *eco-green mathematics* in mathematics education?
5. What are the recommendations for future research directions to strengthen *sustainable mathematical literacy* through a combination of *eco-green mathematics* and AI?

2. Methodology

2.1 Research Design

This study uses Systematic Literature Review (SLR) to answer research questions. SLR is a method of collecting, analyzing, and synthesizing literature relevant to predetermined eligibility criteria (Mengist et al., 2020). This study only focuses on indexed journal articles published in the period 2017–2025. The Preferred Reporting Items for Systematic Reviews and Meta-Analyses approach (Page et al., 2022; Stracke et al., 2023) is used to ensure transparency, accuracy, and replication of the review process. PRISMA consists of four main stages: identification, screening, eligibility, and inclusion, which are described in detail in the following sections. This method was chosen because it is able to provide a comprehensive synthesis of the latest literature related to AI, eco-green mathematics, and sustainable mathematical literacy. The PRISMA flowchart is shown in Figure 1 (modified from Page et al. (2022).

2.2 Systematic Review Process with PRISMA

2.2.1 Identification

Literature searches were conducted on Scopus. The main keywords were derived from the research topics, namely *Artificial Intelligence, Eco-Green Mathematics,* and *Sustainable Mathematical Literacy*. The keyword combination is used in the TITLE-ABS-KEY format. From the initial search process, 146 articles were found. In addition, 15 additional articles were obtained through *citation chaining*, bringing the total number of initial articles to 161 articles.

2.2.2 Screening

The screening process follows the PRISMA guidelines (Page et al., 2022). Duplicate articles are removed, then a selection is made based on titles and abstracts with inclusion and exclusion criteria. At this stage, 57 articles were selected for *full-text review*.

Eligibility and Inclusion

Articles that are irrelevant or do not explain in detail the topics of *eco-green mathematics*, *AI in mathematics education*, or *sustainable mathematics literacy* are eliminated. After a thorough selection based on the content of the article (introduction, methods, results, and

discussion), 34 articles were obtained that met the eligibility and relevance criteria for in-depth analysis.

2.2.3 Data Extraction and Analysis

The data extracted included: author name, year of publication, country, research design, AI technology used, *eco-green mathematics approach*, and its impact on sustainable mathematical literacy. The analysis was carried out thematically with three main focuses:

1. Integration of AI in mathematics learning,
2. Eco-green approach in mathematics education,
3. Strengthening sustainable mathematics literacy.

This entire SLR process is visualized in the PRISMA diagram (Figure 1).

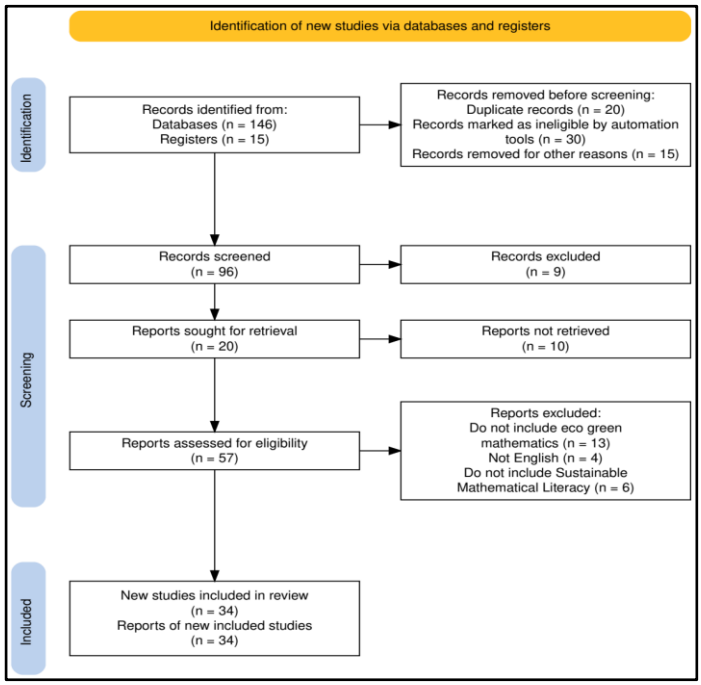

Figure 1. PRISMA Flow Diagram

Various synonyms and alternative terms of the three key terms, namely *eco-green mathematics*, AI in mathematics learning, and *sustainable mathematical literacy*, show the breadth of research perspectives and educational contexts that focus on sustainability and technology. The identification of these terms helps to broaden the scope of the literature search and study analysis, as summarized in Table 1.

Table 1. Synonyms And Alternative Terms for Main Search Terms

Main Term	Synonyms / Alternative Terms
Eco-Green Mathematics	• *Green mathematics* (Mayasari et al., 2019) • *Mathematics for sustainability* (Alsina, 2022; Alsina, 2023) • *Mathematics education for sustainable development (ESD)* (Bulut & Borromeo Ferri, 2025; Karaarslan Semiz & Isler Baykal, 2020) • *Sustainable mathematics curriculum* (Kim & Pang, 2022; Sunzuma & Luneta, 2023)

Main Term	Synonyms / Alternative Terms
AI dalam Pembelajaran Matematika	• *Mathematics applied to SDGs* (Lafuente-Lechuga et al., 2020) • *Environmental mathematics education* (García-Alonso et al., 2023) • *Artificial intelligence in mathematics education* (Opesemowo & Adewuyi, 2024; Zreik, 2024) • *AI-enhanced learning* (Darwish et al., 2025; Li & Manzari, 2025) • *Green AI* (Ahmad et al., 2025; Alzoubi & Mishra, 2024; Bolón-Canedo et al., 2024) • *Intelligent tutoring systems (ITS)* (Opesemowo & Ndlovu, 2024) • *AI literacy in mathematics* (Wijaya et al., 2024) • *AI-integrated mathematics instruction* (Song et al., 2025; Stefanova & Georgiev, 2024) • *AI-supported pedagogy* (Ngoveni, 2025)
Sustainable Mathematical Literacy	• *Mathematical literacy for sustainability* (Chen et al., 2022; Bellini et al., 2019) • *Critical mathematical literacy* (Alsina & Vásquez, 2024) • *Numeracy for sustainable development* (García-Alonso et al., 2023) • *Sustainable numeracy skills* (Bellini et al., 2019) • *21st-century mathematical literacy* (Wijaya et al., 2024) • *Environmental literacy* (Yuniarti et al., 2019) • *Mathematical competencies for SDGs* (Li, 2025; Lucas & Paulo, 2024)

3. Result and Discussion

3.1 Results of Literature Review

3.1.1 Trends and Directions of Eco-Green Mathematics Research in Supporting Sustainable Mathematical Literacy (Goal 1 & RQ1)

Research on eco-green mathematics shows a trend of strengthening the integration of mathematics with sustainability issues. Alsina (2022), Alsina (2023) and Alsina & Vásquez (2024) emphasize that Mathematics Teacher Education for Sustainability (MTEfS) is a new research agenda that is developing to build ecological awareness in prospective mathematics teachers. Studies by Karaarslan Semiz & Isler Baykal (2020) and Bulut & Ferri (2025) found that mathematical modelling plays an important role in linking mathematical concepts with sustainability practices. According to Sunzuma & Luneta (2023) assessing mathematics textbooks in Zimbabwe, identifying improvements but not yet maximizing in the context of sustainability. Meanwhile, Kim & Pang (2022) found that mathematics textbooks in Japan, Korea, and Singapore began to insert sustainable activities based on environmental contexts. Meanwhile, Mayasari et al. (2019) highlight that green mathematics-based learning can foster the character of caring for the environment, while Yuniarti et al. (2019) and Widiati & Juandi (2019) emphasize the importance of ESD competencies in mathematics curriculum at the secondary level.

3.1.2 The Role and Contribution of AI in Mathematics Learning Innovation for Sustainable Literacy (Goal 2 & RQ2)

AI research in mathematics education is growing rapidly in line with the era of the 4th Industrial Revolution (4IR) (Opesemowo & Adewuyi, 2024; Son et al., 2025). AI is not only used to improve learning effectiveness but can also support sustainable education. Studies (Ahmad et al., 2025; Alzoubi & Mishra, 2024; Bolón-Canedo et al., 2024) highlight green AI, which is an energy-efficient and environmentally friendly AI concept. According to Darwish et al. (2025) introduce an AI-enhanced sustainable educational framework that combines smart technology with sustainability values. Research (M. Li & Manzari, 2025; Ngoveni, 2025) show that AI can help personalize mathematics learning in primary to distance education with an ethical and inclusive approach. In addition, Wijaya et al. (2024) found a relationship between AI literacy, teacher confidence, and 21st-century skills that support the development of sustainable mathematical literacy. Zreik (2024) and Stefanova & Georgiev (2024) also highlight the opportunities as well as challenges of AI, such as the need for the integration of ethics, regulation, and teacher competency development.

3.1.3 Models, Approaches, and Best Practices of Integrating Eco-Green Mathematics and AI (Goal 3 & RQ3)

Several studies identified innovative learning models that combine eco-green mathematics with AI. Guan et al. (2024) propose a mathematics-inspired learning model that is interpretable and supports green learning. Asrifan et al. (2025) introduces a new paradigm of AI-based literacy and sustainability, emphasizing the importance of combining adaptive technologies with environmental contexts. Lucas & Paulo (2024) and Lafuente-Lechuga et al. (2020) show that economic and environment-based mathematical modeling is very effective in teaching the concept of the SDGs. Studies (Emon et al., 2024; Darwish et al., 2025) also feature a framework for the integration of AI with green technology for continuous math learning. In addition, Bellini et al. (2019) developed a Mathematical Competence Scale (MCS) to assess continuous numeracy competencies that can be combined with an AI platform.

3.1.4 Challenges and Opportunities for the Application of AI and Eco-Green Mathematics in Mathematics Education (Goal 4 & RQ4)

The main challenges in the application of AI are ethics, data bias, and technology access gaps (Opesemowo & Ndlovu, 2024; Zreik, 2024). According to Song et al. (2025), teacher and student acceptance of AI greatly influences the successful implementation of this technology in the classroom. On the other hand, the great opportunity lies in the personalization of learning and the improvement of numeracy literacy in the 21st century (Wijaya et al., 2024; Ngoveni, 2025). In the context of eco-green mathematics, challenges arise in developing a curriculum that is consistent with the value of sustainability (Sunzuma & Luneta, 2023; Karaarslan Semiz & Isler Baykal, 2020). However, Bulut &

Ferri (2025) shows opportunities for integrating *modelling* based on environmental issues that can increase the ecological awareness of prospective teachers.

3.1.5 Recommendations for Future Research Directions (Goal 5 & RQ5)

Future research directions are suggested to strengthen synergies between AI, eco-green mathematics, and sustainable literacy. Researchers such as Alsina (2022) and Alsina (2023) emphasize the need for a sustainability-based curriculum in mathematics teacher training. Ahmad et al. (2025) and Alzoubi & Mishra (2024) encourage the development of energy-efficient green AI for learning. Son et al. (2025) recommend further research through bibliometric analysis to map AI trends in mathematics learning. Future research also needs to focus on the development of AI-based sustainable mathematical literacy assessment instruments (Bellini et al., 2019; Chen et al., 2022). According to H.-C. Li (2025) and Lucas & Paulo (2024) emphasize the importance of STEM education with a sustainability approach to addressing the challenges of climate change. Thus, the synergy between intelligent technology, pedagogical innovation, and environmental context will be the main pillars of the development of mathematical literacy in the 21st century.

3.2 Discussion

3.2.1 Tren and directions of eco-green mathematics research

Recent literature shows that eco-green mathematics has evolved to become an integral part of Education for Sustainable Development (ESD). Alsina (2022) and Alsina (2023) emphasized the importance of integrating sustainability concepts into the mathematics curriculum, especially in teacher training, through Mathematics Teacher Education for Sustainability (MTEfS). This approach aims to equip prospective teachers with the ability to think critically about global issues, such as climate change and natural resource management (Alsina & Vásquez, 2024). Research (Sunzuma & Luneta, 2023; Kim & Pang, 2022) show that mathematics textbooks in different countries are starting to adopt environmental contexts, although their application is still limited. In addition, Mayasari et al. (2019) highlight green mathematics as a means of building environmentally caring character, while Widiati & Juandi (2019) and Yuniarti et al. (2019) affirm that sustainability competencies at the secondary school level are crucial to support sustainable mathematical literacy.

3.2.2 The role of AI in mathematics learning innovation

The development of artificial intelligence (AI) in the field of mathematics education offers great opportunities in creating more adaptive, personalized, and efficient learning (Opesemowo & Adewuyi, 2024; Son et al., 2025). AI is not only used to automate evaluations, but also forms a learning framework that supports sustainable development. Ahmad et al. (2025), Bolón-Canedo et al. (2024), and Alzoubi & Mishra (2024) introduced the concept of green AI that focuses on energy efficiency and reducing environmental impact. Darwish et al. (2025) describe an AI-enhanced sustainable educational framework

that combines AI with sustainability values, while Ngoveni (2025) and Li & Manzari (2025) emphasize the need for ethics and inclusivity in the application of AI. Research by Wijaya et al. (2024) also links teachers' AI literacy to 21st-century skills, which are important for the development of sustainable mathematical literacy.

3.2.3 Models and best practices for the integration of eco-green mathematics and AI

Several studies propose innovative models that synergize eco-green mathematics with AI technology. Guan et al. (2024) developed a mathematics-inspired learning model that is not only based on understanding mathematical concepts but also supports green learning. Asrifan et al. (2025) promote a new literacy paradigm by combining AI and sustainability, while Lucas & Paulo (2024) and Lafuente-Lechuga et al. (2020) emphasize the use of economics and environment-based mathematical modelling as best practices in teaching the SDGs. Bellini et al. (2019) developed the Mathematical Competence Scale (MCS) to measure continuous numeracy, which can be combined with an AI platform for adaptive learning. These best practices show that integrating AI and *eco-green mathematics* has the potential to improve the quality of learning while strengthening ecological awareness.

3.2.4 Challenges and opportunities for the application of AI and eco-green mathematics

The main challenges found are ethical aspects, algorithm bias, and technology access gaps in various countries (Zreik, 2024; Opesemowo & Ndlovu, 2024). Song et al. (2025) point out that the successful implementation of AI in the classroom is highly dependent on the acceptance of teachers and students, while Stefanova & Georgiev (2024) emphasize the need for teacher training related to the use of AI. On the other hand, the opportunities presented by AI are quite large, especially in strengthening learning personalization and increasing student motivation (Ngoveni, 2025; Wijaya et al., 2024). For eco-green mathematics, the challenge lies in aligning the curriculum with sustainability issues (Sunzuma & Luneta, 2023), but there is a great opportunity to relate learning to the real world through project-based learning based on the environment (Bulut & Ferri, 2025).

3.2.5 Recommendations and directions for future research

The literature emphasizes the need for interdisciplinary research linking AI, eco-green mathematics, and sustainable mathematical literacy. Alsina (2022, 2023) recommends the development of the MTEfS curriculum to equip teachers with sustainability competencies. Ahmad et al. (2025) and Bolón-Canedo et al. (2024) encourage the development of environmentally friendly green AI to support learning. Bibliometric research by Son et al. (2025) and Yıldız & Körpeoğlu (2025) shows that AI research in mathematics education continues to grow, but there is still a gap in the development of sustainable mathematical literacy assessment instruments (Bellini et al., 2019; Chen et al., 2022). Lucas & Paulo (2024) and Li (2025) emphasize the importance of sustainability-based STEM approaches to addressing the challenges of climate change. Thus, the future

of sustainable mathematical literacy will depend on the synergy of smart technologies, pedagogical innovation, and the integration of environmental values.

3.2.6 Implications for Teachers and Learning

The results of the study show that mathematics teachers need to develop dual competencies: sustainability literacy (eco-green literacy*)* and AI-based technology literacy. Teachers are expected to be able to design learning that relates mathematical concepts to the environmental context, such as carbon emission data analysis, resource management, or simulations of renewable energy calculations (Alsina, 2023; Karaarslan Semiz & Isler Baykal, 2020). In addition, the use of AI such as adaptive learning systems and intelligent tutoring systems can help teachers personalize learning according to students' abilities (Li & Manzari, 2025; Song et al., 2025). This implication requires continuous training so that teachers not only master technology, but can also integrate it with sustainability values to form sustainable mathematical literacy.

3.2.7 Implications for Curriculum and Policy

At the curriculum level, the results of this SLR recommend the development of mathematical content that is more relevant to global issues such as the SDGs, climate change, and economic sustainability, by utilizing mathematical modelling based on environmental data (Lucas & Paulo, 2024; Lafuente-Lechuga et al., 2020). Meanwhile, in terms of policy, regulatory support is needed for the implementation of energy-efficient green AI and the provision of technological infrastructure in schools (Ahmad et al., 2025; Bolón-Canedo et al., 2024). Governments and educational institutions can adopt a Mathematics Teacher Education or Sustainability (MTEfS) teacher training model (Alsina & Vásquez, 2024) and ensure that mathematics learning is able to answer the challenges of digitalization while building ecological awareness in students.

3.3 Research Limitations and Future Research Directions

3.3.1 Research Limitations

This study was limited to 34 Scopus indexed articles that focused on eco-green mathematics*,* AI in mathematics learning, and sustainable mathematical literacy. A major limitation is that it has not included research in local languages or non-Scopus publications that have the potential to provide contextual insights, particularly on educational practices in developing countries. In addition, most studies are still conceptual or literature studies without empirical evidence in real classes, so the generalization of results in different contexts is limited (Alsina, 2023; Zreik, 2024). The study has also not explored in depth the ethical issues of AI use, such as data privacy and algorithm bias, which are actually important aspects of the implementation of smart technologies in education.

3.3.2 Future Research Directions

Future research needs to expand the scope of literature sources, including experiment-based studies that evaluate the effectiveness of integrating AI and eco-green mathematics at various levels of education. Future research directions can also be focused on the development of AI-based sustainable mathematical literacy assessment instruments, such as the continued development of the Mathematical Competence Scale (MCS) (Bellini et al., 2019). In addition, research needs to explore the implementation of energy-efficient green AI (Ahmad et al., 2025) and test collaborative learning models based on mathematical modeling with sustainability issues in various cultural contexts (Lucas & Paulo, 2024; Li, 2025). Cross-border and interdisciplinary studies are also highly recommended to map the synergies of AI, green pedagogy, and SDGs-based curricula globally.

4. Conclusion

4.1 Synthesis of Key Findings

The results of this study confirm that the integration of eco-green mathematics *and* artificial intelligence (AI) plays an important role in the development *of* sustainable mathematical literacy. Previous research has shown that the eco-green mathematics approach has succeeded in linking mathematics learning with sustainability issues, such as environmental management and the achievement of the SDGs (Alsina, 2022; Karaarslan Semiz & Isler Baykal, 2020; Sunzuma & Luneta, 2023). On the other hand, AI is present as a catalyst for learning innovation through personalization, automation, and data-driven analytics, while encouraging the concept of green AI that is environmentally friendly (Ahmad et al., 2025; Bolón-Canedo et al., 2024). The combination of these two approaches opens up great opportunities to improve mathematical literacy relevant to global challenges.

4.2 Challenges and Opportunities

Nonetheless, a number of challenges were identified, such as limited access to technology, lack of AI literacy among teachers, and the need for a curriculum that is consistent with sustainability values (Zreik, 2024; Opesemowo & Ndlovu, 2024). Several studies highlight that teacher and student acceptance of AI technology is a key factor for successful integration in mathematics learning (Song et al., 2025; Wijaya et al., 2024). On the other hand, great opportunities come through the development of environment-based mathematical modelling (Lucas & Paulo, 2024; Lafuente-Lechuga et al., 2020) as well as the implementation of ethical and energy-efficient AI frameworks (Darwish et al., 2025). An interdisciplinary approach between mathematics pedagogy, technology, and sustainability values is seen as the foundation of the future of education.

4.3 Implications and Future Research Directions

This study recommends that future research should place more emphasis on the development of learning models that synergize eco-green mathematics with AI technology to improve 21st century skills and ecological awareness. Researchers such as Alsina (2023) and (H.-C. Li, 2025) encourages the integration of sustainability values in curriculum and teacher training, while bibliometric studies by Son et al. (2025) and Yıldız & Körpeoğlu (2025) suggest that AI will become a major trend in mathematics education. In addition, the development of AI-based sustainable mathematical literacy evaluation instruments, such as the Mathematical Competence Scale (Bellini et al., 2019), is expected to strengthen research in this field. Therefore, the synergy of smart technology, green curriculum, and pedagogical innovation will be the key to building sustainable mathematical literacy in the digital era.

5. Acknowledgement

The Fundamental Regular Research Team sincerely expresses its gratitude to **DPPM Kemdiktisaintek 2025** for the funding support provided through the 2025 Fundamental Regular Research Scheme. We also extend our appreciation to the Institute for Research and Community Service (LPPM) of Universitas Islam Malang for their valuable support.

6. Recomendations

6.1 For Teachers

1. **Integration of Environmental Context in Mathematics Learning**
   Teachers are advised to relate mathematics materials to environmental issues such as renewable energy, climate change, or waste management through project-based learning *and* mathematical modelling (Lucas & Paulo, 2024; Alsina, 2023).
2. **Utilization of AI for Learning Personalization**
   Use AI-based tools such as intelligent tutoring systems to tailor learning to students' abilities and speed, while introducing energy-efficient green AI concepts (Li & Manzari, 2025; Bolón-Canedo et al., 2024).
3. **Strengthening Teacher Competence through Continuous Training**
   Teachers can join professional development programs such as Mathematics Teacher Education for Sustainability (MTEfS) to strengthen sustainability competencies while also understanding the potential and limitations of AI in the classroom (Alsina & Vásquez, 2024).

6.2 For Policymakers

1. **SDGs-Based Curriculum Reform**
   Curriculum policies need to include the concept of eco-green mathematics and the application of smart technology to support the achievement of sustainable development goals (Lafuente-Lechuga et al., 2020; Tesfamicael & Enge, 2024).

2. **Provision of AI Infrastructure and Access**
   The government and educational institutions must ensure technological infrastructure and connectivity that supports the use of AI in schools, especially for areas with technology limitations (Ngoveni, 2025; Zreik, 2024).
3. **Ethical Regulations for the Use of AI in Education**
   Design policies that ensure the ethical, safe, and environmentally friendly use of AI, in accordance with *green AI* principles to avoid negative impacts such as algorithm bias or excessive energy consumption (Ahmad et al., 2025; Alzoubi & Mishra, 2024).

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