Journal of Theoretical and Empirical Studies in Education
Vol. 10 Issue 2 May, 2025

Green AI in Education: Can Artificial Intelligence Promote Sustainable Learning?

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Abstract
As the global community grapples with escalating environmental challenges, the imperative to integrate sustainability into every facet of society has never been more urgent. Education is integral to this transformation, and recent advancements in artificial intelligence (AI) offer promising avenues for promoting sustainable learning. This review paper investigates the emerging field of "Green AI in Education," focusing on how AI-driven technologies can foster climate literacy, support green behaviour modelling, and provide robust environmental decision-making tools. By synthesising interdisciplinary research across computer science, environmental studies, and pedagogy, this paper identifies the potential benefits and pitfalls of implementing AI solutions in education. Key discussions include the design of energy-efficient algorithms (Green AI), strategies for embedding sustainability within educational content, and the ethical and practical challenges associated with deploying AI in learning environments. The review concludes with recommendations for future research and policy initiatives aimed at harnessing AI's power to promote sustainability while ensuring that technological innovation remains aligned with environmental goals.
Keywords: Green AI, Sustainable Learning, Climate Literacy, AI-Driven Education, Environmental Decision-Making

Introduction

In recent years, the concept of sustainability has moved to the forefront of global discourse, influencing public policy, business strategies, and educational practices (Abo-Khalil, 2024; Membrillo-Hernández, Lara & Caratozzolo, 2021; Thun *et al*., 2024). The transition toward a sustainable future is inherently multifaceted, involving ecological conservation, socio-economic equity, and responsible resource management. At the intersection of these themes lies education, a cornerstone for societal transformation (International Panel on Social Progress, 2018). Educational institutions not only serve as repositories of knowledge but also as catalysts for change, shaping how future generations understand and interact with the environment (Børresen *et al*., 2022; World Bank Group, 2024).

Simultaneously, artificial intelligence (AI) has experienced exponential growth, evolving from a niche area of research into a transformative technology with broad applications (Rashid and Kausik, 2024). Traditionally, the integration of AI in education has centered on personalised learning, adaptive assessment, and administrative efficiency (Deep, Athimoolam & Enoch, 2024; Iqbal, 2023; Plooy, Casteleijn & Franzsen, 2024). However, a new narrative has emerged, one that considers the role of AI in promoting sustainable learning. This review paper explores this narrative by examining how AI can be utilised to enhance climate literacy, model green behaviour, and support environmental decision-making processes.

The concept of "Green AI" itself has garnered attention as researchers and developers seek to design algorithms that are not only intelligent but also energy-efficient and environmentally friendly. This dual focus on performance and sustainability challenges the traditional view of AI development, urging the community to consider the broader ecological implications of computational practices. In the context of education, Green AI holds the promise of embedding sustainability into learning environments in ways that are both innovative and responsible.

This review is structured as follows. Section 2 provides an overview of the current literature on Green AI and its applications in education, outlining key definitions and historical perspectives. Section 3 explores the technological underpinnings of AI-driven climate literacy, discussing the methods and tools employed to integrate environmental data into educational frameworks. Section 4 focuses on green behaviour modelling, analysing how AI can simulate and encourage sustainable practices among learners. Section 5 reviews environmental decision-making tools, highlighting AI applications that facilitate real-world sustainability planning and policy formulation. Section 6 discusses the challenges, ethical considerations, and potential limitations of implementing Green AI in educational settings. Finally, Section 7 presents conclusions and recommendations for future research and policy initiatives, summarising the potential of AI to promote sustainable learning and identifying key areas for further exploration.

Literature Review: From AI in Education to Green AI

Historical Context and Evolution

The application of artificial intelligence in education is not new. Early efforts in computer-assisted instruction and intelligent tutoring systems laid the groundwork for today's sophisticated AI-driven educational platforms. Historically, AI in education focused on automating administrative tasks, enhancing student engagement through adaptive learning, and providing personalised feedback to improve learning outcomes (Iqbal, 2023, Plooy, Casteleijn& Franzsen, 2024; Deep, Athimoolam & Enoch, 2024). The evolution from these early systems to modern AI applications has been driven by advances in machine learning algorithms, increased computational power, and the availability of large datasets.

More recently, the emergence of environmental challenges has spurred interest in how AI can support sustainability initiatives. In this context, "Green AI" represents a paradigm shift, focusing on the design and implementation of AI systems that prioritise energy efficiency and reduced carbon footprints while still delivering high performance. Researchers such as Schwartz *et al*. (2020) and Hao (2019) have highlighted the environmental cost of training large AI models, prompting a re-evaluation of algorithmic efficiency and energy consumption. This critique has catalyzed the development of more sustainable AI methodologies, which are now being considered for integration into various sectors, including education.

The concept of sustainable learning integrates environmental education with technological innovation. Educational institutions have increasingly recognised the importance of climate literacy in the understanding of climate change science, its impacts, and the socio-economic implications of environmental degradation. AI-driven systems offer the potential to deliver this content in interactive, engaging, and personalised formats. By bridging the gap between technological prowess and environmental responsibility, Green AI in education aims to cultivate a generation of learners who are both tech-savvy and environmentally conscious.

Defining Green AI

Green AI is an emerging area of research that emphasises the development of algorithms and models that are not only effective in their performance but also optimised for energy efficiency and minimal environmental impact (Barbierato and Gatti, 2024 and Schwartz *et al*., 2020). This approach contrasts with traditional "red AI" methods that often prioritise model complexity and performance without accounting for the associated computational and energy costs (Barbierato & Gatti, 2024). In the context of education, the adoption of Green AI is twofold: it is about creating AI tools that are sustainable in their own right and using those tools to teach and promote sustainable practices.

A key aspect of Green AI is the measurement of computational efficiency and environmental impact (Barbierato and Gatti, 2024 and Schwartz *et al*., 2020). Metrics such as the amount of energy consumed during training and inference, the carbon footprint of data centers, and the efficiency of algorithmic processes are increasingly being incorporated into research evaluations. These considerations are vital in ensuring that AI applications do not inadvertently contribute to environmental degradation. When applied to educational technologies, Green AI requires a thoughtful balance between pedagogical effectiveness and environmental sustainability.

Integrating Sustainability into Educational Frameworks

Sustainable education goes beyond the mere transmission of knowledge. It involves cultivating a mindset and a set of practices that contribute to environmental stewardship (Henriksen, Mishra& Stern, 2024). Traditional curricula have often treated environmental education as an ancillary subject, confined to specific courses or extracurricular activities. However, the integration of sustainability into the core curriculum has gained traction, with educational institutions recognising that understanding sustainability is essential for addressing global challenges.

AI-driven platforms can play a significant role in this integration by providing adaptive learning environments that incorporate real-time environmental data, simulate ecological scenarios, and offer personalised feedback based on individual learning progress (Kabudi, Pappas & Olsen, 2021; Strielkowski *et al*., 2024; Tabuenca *et al*., 2024). For instance, virtual laboratories powered by AI can allow students to experiment with ecological models, observe the impact of human activities on climate systems, and explore sustainable solutions in a controlled setting (Cho & Park, 2023; Poo, Lau & Chen, 2023). Such experiential learning opportunities are crucial in fostering a deep understanding of environmental issues and promoting green behaviour.

Intersection of AI, Sustainability, and Education

The convergence of AI, sustainability, and education creates a fertile ground for innovation and interdisciplinary research. Recent studies have explored various dimensions of this intersection. For example, research by Wang *et al*. (2021) investigated the use of machine learning algorithms to analyse climate data, while

Cao and Jian (2024) explored its role in delivering personalised environmental education. Their findings suggest that AI can significantly enhance the effectiveness of climate literacy programs by tailoring content to the needs and learning styles of individual students.

Similarly, studies on green behaviour modelling have shown that AI can simulate complex social and environmental systems, providing insights into how individual and collective actions contribute to sustainability outcomes (Cao & Jian, 2024; Lane, 2024). By modelling scenarios such as energy consumption, waste management, and resource allocation, AI systems can help learners understand the trade-offs and consequences of different behaviours. This form of simulation-based learning is particularly valuable in fostering critical thinking and problem-solving skills.

Environmental decision-making tools represent another promising application of AI in education (Konya & Nematzadeh, 2024). These tools leverage advanced analytics and predictive modelling to inform policy decisions and resource management strategies. When integrated into educational programs, they offer students a hands-on understanding of how data-driven decision-making can contribute to sustainable practices. By engaging with these tools, learners can develop a nuanced appreciation for the complexities of environmental policy and the role of technology in addressing real-world challenges. Table 1 provides a summary of how different aspects of Green AI in education intersect with technological methods, pedagogical benefits, and the associated challenges. It can serve as a quick reference guide for educators, policymakers, and researchers interested in understanding and advancing sustainable learning through AI.

Table 1: Key Dimensions of Green AI in Education

Component	Description	AI Techniques/Tools	Educational Benefits	Challenges/Limitations	References
Climate Literacy	Enhancing understanding of climate science through dynamic, data-driven educational tools.	Natural Language Processing (NLP), Computer Vision, Virtual/Augmented Reality (VR/AR), Simulation Models	Improved comprehension of complex climate phenomena; Real-time data visualisation enhances engagement and retention.	Data accuracy and availability; Integration of real-time analytics into existing curricula; Technological barriers in resource-constrained environments.	Liu *et al*., 2020; Huang, 2018; Dai & Ke, 2022
Green behaviour Modelling	Simulating and promoting sustainable practices by visualising the long-term environmental impacts of individual and collective actions.	Agent-Based Modelling (ABM), Deep Learning, Simulation Environments	Enables experiential learning; Provides personalised feedback; Encourages critical thinking about sustainable choices.	Requires robust behavioural data; Balancing simulation complexity with user accessibility; Potential oversimplification of real-world scenarios.	Huang, 2018; Dai & Ke, 2022 ; Tian *et al*., 2021
Environmental Decision-Making	Integrating AI tools to support evidence-based policy and resource management decisions, enabling students to explore trade-offs in	Predictive Analytics, Optimisation Algorithms, Decision Support Systems	Fosters data literacy and critical thinking; Offers hands-on experience with policy simulation and resource allocation strategies.	Ensuring model transparency and addressing algorithmic bias; Complexity in accurately simulating real-world decision-making dynamics; Ethical concerns.	Ncube & Ngulube, 2024 ; Adepoju *et al*., 2024

	sustainability planning.				
Green AI Development	Designing AI systems with a focus on energy efficiency and reduced environmental impact while maintaining high-performance capabilities.	Model Compression, Energy-Efficient Algorithm Design, Use of Renewable-Powered Data Centers	Aligns technology development with sustainability goals; Reduces the environmental footprint of AI applications in education.	Balancing performance with energy efficiency; Measuring and standardising environmental impact metrics; Limited adoption of green practices across institutions.	Tabbakh *et al*., 2024; Zhuk, 2023
Data Integration & Real-Time Analytics	Combining diverse datasets (e.g., environmental, socio-economic) to provide cohesive and up-to-date educational content that reflects current environmental conditions.	Data Fusion Techniques, Real-Time Analytics, Cloud-Based Platforms	Ensures that learning materials remain current and contextually relevant; Promotes interdisciplinary understanding of sustainability.	Data quality and integration challenges; Infrastructure requirements for handling large, dynamic datasets; Ensuring data privacy and security.	Himeur *et al*., 2022

AI-Driven Climate Literacy: Tools, Techniques, and Applications

The Imperative of Climate Literacy

Climate literacy is an essential component of sustainable education. It encompasses not only the scientific understanding of climate change but also the socio-economic, political, and ethical dimensions of environmental issues. In today's rapidly changing world, equipping students with a comprehensive understanding of climate science is imperative. AI offers several tools and techniques that can enhance climate literacy by making complex data accessible, interactive, and engaging (Atkins *et al*., 2024 and Jain *et al*., 2023).

Climate literacy involves a deep understanding of key concepts such as greenhouse gas emissions, global warming potential, and the impact of human activities on natural systems (Johnston, 2018). Traditional educational approaches have often relied on static textbooks and lectures to convey this information. However, AI-driven systems can transform this learning process by integrating dynamic data sources, interactive visualisations, and real-time analytics.

AI Techniques for Enhancing Climate Education

A range of AI techniques have been employed to support climate education. Among these, natural language processing (NLP) and computer vision play significant roles (Liu *et al*., 2020). NLP algorithms can analyze vast amounts of climate-related literature, extract key insights, and generate summaries that are tailored to different learning levels. For instance, AI-powered chatbots can provide students with on-demand explanations of complex climate phenomena, adapting responses based on the learner's prior knowledge.

Computer vision techniques, on the other hand, enable the analysis and visualization of environmental data. Satellite imagery, for example, can be processed using deep learning algorithms to monitor deforestation, urban sprawl, and changes in land use. These visual tools not only provide empirical evidence of climate change but also serve as powerful educational aids, helping learners visualise the impacts of environmental degradation.

Simulation-based learning environments are another promising application of AI in climate literacy (Dai & Ke, 2022; Huang, 2018). By creating virtual scenarios that replicate real-world environmental processes, AI systems can offer immersive learning experiences. In these simulations, students can experiment with variables such as carbon emissions, renewable energy adoption, and policy interventions, observing how changes affect climate outcomes. This hands-on approach fosters a deeper understanding of cause-and-effect relationships in environmental systems and encourages active engagement with sustainability issues.

Interactive Platforms and Virtual Laboratories

The development of interactive learning platforms has been a significant focus of recent research in AI-driven education. These platforms integrate various AI techniques to create immersive and adaptive learning experiences (Kabudi, Pappas & Olsen, 2021; Strielkowski *et al*., 2024; Yaseen *et al*., 2025). Virtual laboratories, for example, allow students to engage with climate data in real time. In these settings, learners can manipulate variables, run simulations, and observe the outcomes, thereby gaining practical insights into the complexities of climate science. One notable application involves the use of virtual reality (VR) and augmented reality (AR) to simulate environmental phenomena (Cosio *et al*., 2023; Negi, 2024). By leveraging AI algorithms that dynamically adjust simulation parameters based on user interactions, these platforms can provide personalised learning experiences. For example, a VR simulation might allow students to experience the effects of sea-level rise on coastal communities, complete with interactive models that show potential mitigation strategies. The immersive nature of these platforms enhances comprehension and retention, making abstract climate concepts more tangible and relatable (Negi, 2024).

Data Integration and Real-Time Analytics

The effectiveness of AI-driven climate literacy tools often hinges on their ability to integrate diverse data sources. Environmental data is inherently complex, encompassing meteorological records, satellite observations, and socio-economic indicators. AI algorithms can harmonise these disparate datasets, providing a cohesive narrative that informs learners about the multifaceted nature of climate change (see Figure 1) (Islam *et al*., 2024; Miller *et al*., 2025).

Real-time analytics also play a crucial role in this integration. By processing live data streams, AI systems can update simulations and visualisations to reflect current environmental conditions (UNEP, 2022). This dynamic updating not only keeps educational content relevant but also instills an appreciation for the evolving nature of climate science. For instance, during periods of significant environmental events—such as wildfires or hurricanes—real-time data can be used to illustrate the immediate impacts of climate change, thereby reinforcing the urgency of sustainable practices.

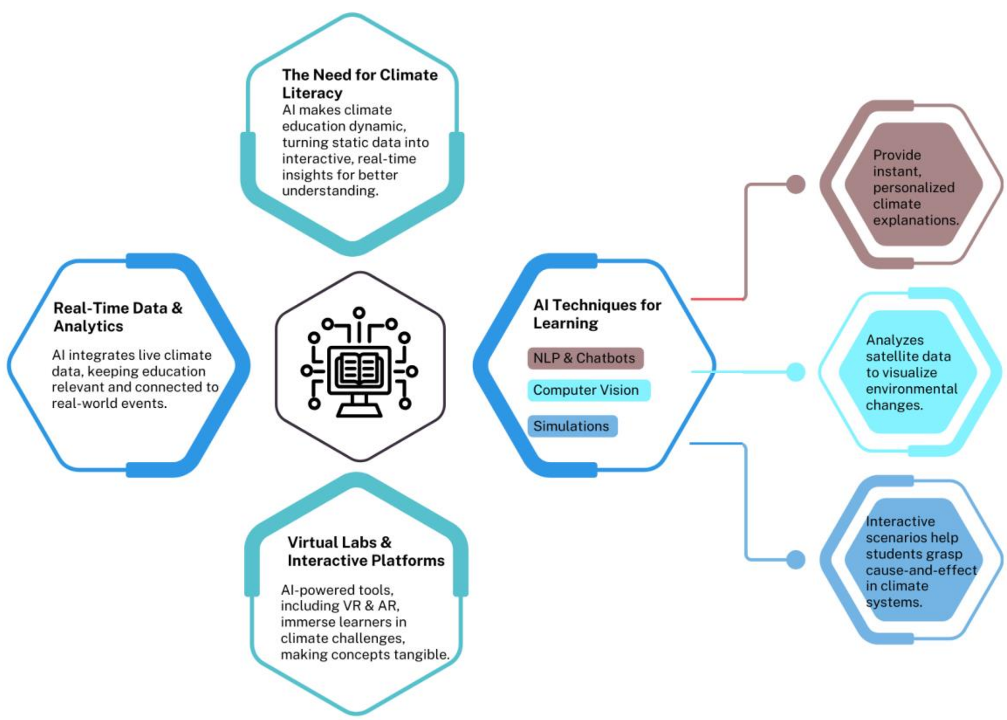

Figure 1: AI-Driven Climate Literacy: Tools & Techniques

Green Behaviour Modelling: Simulating and Promoting Sustainable Practices

The Importance of behaviour in Sustainability

Behavioural change is a critical component of sustainability (Klaniecki, Wuropulos, & Hager, 2019). While knowledge of environmental issues is essential, it is the translation of this knowledge into sustainable actions that ultimately drives positive change. Green behaviour modelling refers to the use of AI systems to simulate and encourage environmentally friendly practices. By modelling the potential impacts of individual and collective behaviours, AI can help learners visualise the long-term consequences of their actions on the environment (Cao & Jian, 2024; Henriksen, Mishra & Stern, 2024).

Understanding human behaviour in the context of sustainability involves a complex interplay of psychological, social, and economic factors. Traditional methods of behaviour analysis have often relied on surveys, observational studies, and statistical models. AI, with its ability to analyse large datasets and identify patterns, offers a powerful alternative. Machine learning algorithms can predict behavioural trends, simulate the effects of policy interventions, and provide insights into how sustainable practices can be adopted at scale (Kolkman, 2020; Mrabet & Sliti, 2024, Sarker, 2021;).

AI Methods for behaviour Modelling

A variety of AI techniques have been deployed to model green behaviour. Agent-based modelling (ABM) is one such method that simulates the interactions of autonomous agents within a defined environment (Doumpos *et al*., 2023). In the context of sustainability, these agents can represent individuals, households, or even organisations, each with their own set of behaviours and decision-making processes. By simulating interactions between these agents, researchers can explore how changes in behaviour at the micro level influence macro-level environmental outcomes. Deep learning models also offer significant potential in behaviour modelling. Neural networks, when trained on datasets encompassing consumer behaviour, energy usage, and environmental indicators, can predict future trends and identify key drivers of sustainable practices (Aljohani, 2024; Olawade *et al*., 2024). These models are particularly useful in identifying non-linear relationships that traditional statistical methods might overlook. For example, a deep learning model might reveal that small changes in consumer behaviour, when aggregated across millions of individuals, can lead to significant reductions in carbon emissions.

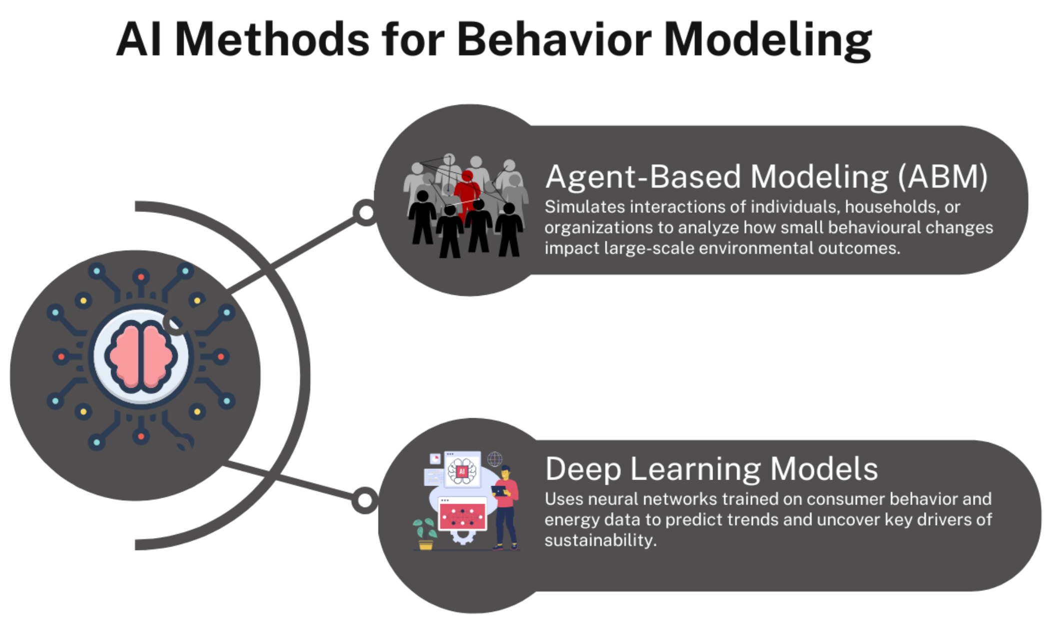

Figure 2: AI Methods for Behaviour Modelling

Simulation Environments for Green behaviour

Simulation environments provide an interactive and engaging way for learners to understand the impact of their actions on the environment (Cho & Park, 2023). AI-powered simulations can create virtual communities where students experiment with different behaviours—such as energy conservation, recycling, and sustainable consumption—and observe the resulting environmental effects. These simulations serve as a microcosm of real-world ecological systems, allowing learners to see the cumulative impact of individual decisions.

One prominent example is a simulation tool that models household energy consumption. In this virtual environment, learners can adjust parameters such as appliance efficiency, insulation quality, and energy usage patterns (Villanueva *et al*., 2022). The simulation then calculates the overall energy consumption and corresponding carbon emissions, offering immediate feedback on how specific actions contribute to broader sustainability goals. Such experiential learning tools are instrumental in demonstrating the practical implications of sustainable behaviour.

Feedback Mechanisms and Adaptive Learning

A key advantage of using AI in behaviour modelling is the ability to provide immediate, personalised feedback (Wang *et al*., 2024). Adaptive learning systems can monitor a student's interactions with simulation environments and adjust the difficulty or focus of tasks based on individual progress (Wang *et al*., 2024). This personalised approach not only enhances learning outcomes but also encourages students to experiment with different strategies for achieving sustainable behaviour. For instance, an AI-driven platform might track a student's choices in a simulated urban planning exercise. Based on the outcomes of these choices—such as improvements in air quality or reductions in energy consumption—the system can offer tailored recommendations for further optimising sustainable practices. This feedback loop not only reinforces positive behaviours but also helps learners understand the underlying principles of sustainability in a concrete, data-driven manner.

Empirical Evidence and Case Studies

Empirical studies have begun to demonstrate the effectiveness of AI-driven behaviour modelling in educational settings. One notable study conducted in North America involved a simulation-based curriculum designed to teach high school students about sustainable urban development. Students engaged with an AI-powered simulation that modeled traffic flow, energy consumption, and environmental pollution. The results indicated a measurable improvement in students' ability to predict the environmental impact of urban planning decisions, as well as an increased propensity to adopt sustainable behaviours in real-life scenarios. Another study in Europe focused on the use of AI to model energy conservation behaviours in residential communities. The simulation allowed students to experiment with different strategies for reducing household energy consumption, such as the adoption of renewable energy sources and the implementation of energy-saving measures. Feedback from participants suggested that the hands-on, interactive nature of the simulation significantly enhanced their understanding of the relationship between individual actions and collective environmental outcomes.

Environmental Decision-Making Tools: AI Applications in Policy and Practice

The Role of Decision-Making in Sustainability

Environmental decision-making is a complex process that involves balancing economic, social, and ecological factors. Whether at the municipal, national, or global level, policymakers are required to make decisions that have far-reaching implications for sustainable development (Li, Lam and Cui, 2021, Olawade *et al*., 2024 and Santos and Carvalho, 2025).

For learners, engaging with these tools provides a practical framework for understanding the challenges and trade-offs inherent in environmental decision-making. By exploring simulated policy scenarios, students can develop a nuanced appreciation for the complexities of sustainability planning and the role of technology in facilitating effective governance.

AI Techniques in Environmental Decision Support

Environmental decision-making tools leverage several advanced AI techniques. Predictive analytics, for example, uses historical and real-time data to forecast future environmental conditions under different scenarios (Idrees *et al*., 2019). These forecasts can inform policy decisions by highlighting potential outcomes of various intervention strategies. Machine learning models have been used to predict phenomena such as air quality, water resource availability, and the spread of wildfires, which are all factors that are critical in environmental planning. Optimisation algorithms are another critical component of decision support systems. These algorithms can identify the most efficient allocation of resources or the optimal mix of renewable energy sources to achieve sustainability targets (Shaier *et al*., 2025). In educational settings, interactive optimisation tools allow students to experiment with different resource allocation strategies, providing insights into the challenges of balancing economic and environmental priorities.

Case Studies in AI-Enabled Policy Simulation

Several real-world examples illustrate the utility of AI in environmental decision-making. A notable initiative is the European Union's "Destination Earth" project, which aims to develop a high-precision digital twin of the Earth. This AI-driven simulation integrates vast amounts of environmental data to model climate change effects and natural disasters, providing policymakers with a tool to test and implement effective environmental policies (Hoffmann *et al*., 2023).

In Sweden, researchers at KTH Royal Institute of Technology have developed an AI-based decision support system for urban planning. This system integrates data on traffic patterns, air quality, and public health to simulate the impact of various urban development plans, aiming to facilitate more sustainable urban designs (Digital Futures, n.d.; Page *et al*., 2020).

In the United States, the Department of Energy (DOE) has launched the Artificial Intelligence for Interconnection (AI4IX) program. This initiative seeks to expedite the integration of renewable energy sources into the power grid by employing AI to streamline the interconnection process, thereby reducing delays and enhancing grid efficiency (American Public Power Association, 2024). Another example is the ARIES (Artificial Intelligence for Environment & Sustainability) project, hosted by the Basque Centre for Climate Change in Spain. ARIES utilises AI to integrate scientific data and models, facilitating comprehensive environmental sustainability assessments and aiding in policy-making decisions (ARIES, 2022).

In Thailand, the National Water Resource Committee (NWRC) has adopted AI to enhance water resource management. The AI system enables real-time monitoring and forecasting, helping authorities manage national water data, improve distribution efficiency, and prevent floods and droughts (Pattaya Mail, 2024). These case studies demonstrate the practical application of AI in policy simulation, contributing to sustainable urban planning, effective water resource management, renewable energy integration, and comprehensive environmental assessments.

Integrating Decision-Making Tools into Educational Curricula

The incorporation of environmental decision-making tools into educational curricula represents a significant advancement in sustainability education. By engaging with these tools, students are exposed to the practical challenges of policy formulation and the role of technology in addressing environmental issues. Curricula that integrate AI-based decision support systems often include case studies, simulation exercises, and project-based learning modules that encourage students to develop and test their own policy proposals (Dai & Ke, 2022; Rebelo, 2025; Zhao, Li & Kang, 2024).

One innovative educational initiative involved collaboration between a government agency and a university, resulting in a series of workshops where students used an AI-driven decision-making tool to simulate responses to environmental crises. Participants were tasked with designing intervention strategies for scenarios such as urban heat islands and flood risk management. The hands-on experience not only deepened their understanding of environmental dynamics but also fostered critical thinking and collaborative problem-solving skills.

Assessing the Impact of AI-Driven Decision-Making in Education

The impact of AI-driven environmental decision-making tools on student learning outcomes has been the subject of several empirical studies. Research indicates that these tools can enhance critical thinking, improve data literacy, and increase awareness of the complex trade-offs inherent in sustainability planning. Students who engage with decision-making simulations tend to demonstrate a greater capacity for integrating multidisciplinary data and are better prepared to navigate the challenges of real-world environmental policymaking (Fasco *et al*., 2024; Vlachopoulos & Makri, 2017).

Challenges, Ethical Considerations, and Limitations

Technical Challenges in Implementing Green AI

Despite the promising potential of Green AI in education, several technical challenges remain. One major challenge is the computational intensity of many AI algorithms (Zhuk, 2023). While Green AI aims to reduce energy consumption and carbon emissions, achieving these goals often requires rethinking conventional algorithm design. Developing energy-efficient models without sacrificing accuracy or functionality is a delicate balance that continues to challenge researchers.

Data quality and availability also pose significant hurdles (Ali *et al*., 2024).

The integration of real-time environmental data with educational platforms requires robust data pipelines and reliable data sources. Inaccuracies or gaps in the data can lead to flawed simulations and misinformed decision-making processes. Ensuring data integrity is therefore paramount, particularly when these tools are used in academic settings where accuracy is critical for educational outcomes.

Ethical Implications and Bias

The ethical implications of deploying AI in education, particularly in the realm of sustainability, are multifaceted. One concern is the potential for algorithmic bias (Ali *et al*., 2021). AI systems are only as good as the data on which they are trained, and if these data sets contain biases, whether cultural, socio-economic, or geographical, the resulting models may perpetuate or even exacerbate these disparities. In the context of environmental decision-making, biased models could lead to recommendations that favor certain communities over others, thereby undermining the equity that is central to sustainable development.

Privacy is another critical ethical consideration (Ali *et al*., 2021). The integration of real-time data into educational platforms raises questions about data security and student privacy. Ensuring that sensitive information is protected is essential, particularly in light of increasingly stringent data protection regulations around the world. Educational institutions and developers must navigate these ethical concerns carefully, balancing the benefits of AI-driven insights with the imperative to protect individual rights.

Practical and Pedagogical Limitations

From a pedagogical perspective, integrating Green AI into educational curricula is not without challenges. Educators may face a steep learning curve in understanding and effectively utilising these advanced tools. Professional development and training are necessary to ensure that teachers can integrate AI-driven content into their lesson plans in a manner that is both effective and engaging (Ding *et al*., 2024).

Furthermore, the availability of technological resources varies widely across different educational institutions and regions. In under-resourced environments, the implementation of advanced AI tools may be hindered by a lack of infrastructure, funding, or technical support. This digital divide has implications for equity in education, as students in resource-limited settings may be deprived of the benefits of cutting-edge, sustainable learning technologies.

Balancing Innovation with Environmental Impact

A critical paradox in the development of Green AI is the need to balance technological innovation with environmental responsibility. While AI has the potential to advance sustainable education, its development and deployment can also have environmental costs (Barbierato & Gatti, 2024; Schwartz *et al*., 2020). High-performance computing, large-scale data centers, and intensive training processes contribute to energy consumption and carbon emissions. Researchers and developers must therefore continually innovate to reduce the environmental footprint of AI systems while maintaining their efficacy.

Strategies for addressing this challenge include the adoption of model compression techniques, the use of renewable energy sources for data centers, and the development of algorithms specifically optimised for energy efficiency. Balancing these competing demands is essential for ensuring that the pursuit of technological advancement does not undermine the environmental objectives that underpin sustainable education.

Future Directions and Recommendations

Advancing Research in Green AI

The future of Green AI in education lies in interdisciplinary collaboration and ongoing innovation. Researchers from computer science, environmental studies, and pedagogy must work together to develop models that are both energy-efficient and pedagogically effective. Prioritizing research on algorithmic efficiency, data integration, and adaptive learning will be key to advancing the field.

Developing standardised metrics for evaluating the environmental impact of AI systems is another important area for future research. Such metrics would allow for more objective comparisons between different models and facilitate the broader adoption of sustainable AI practices in educational settings. Funding agencies and academic institutions should encourage research proposals that emphasise sustainability alongside technical performance.

Enhancing Educational Infrastructure

Investing in the educational infrastructure necessary to support AI-driven sustainable learning is paramount. This includes not only the hardware and software needed to run advanced simulations and data analytics but also comprehensive professional development programs for educators. Institutions should develop partnerships with technology companies, government agencies, and non-profit organisations to secure resources and expertise in the field.

Curricular reform is also essential. Integrating sustainability as a core component of the educational framework requires a shift in pedagogical approaches (Gamage, Ekanayake & Dehideniya, 2022). Educational curricula should incorporate modules on climate science, sustainable behaviour, and environmental policy, supported by interactive, AI-driven learning tools. Such reforms will help prepare students to navigate the complexities of a rapidly changing world.

Policy Implications and Collaborative Initiatives

Policy initiatives that support the integration of Green AI in education are critical for scaling its impact (Cao & Jian, 2024; Nedungadi, Tang, & Raman, 2024).

Governments and educational authorities should consider policies that incentivise the development and adoption of energy-efficient AI technologies. Such policies might include grants for research on Green AI, tax incentives for institutions adopting sustainable technologies, and frameworks for ensuring data privacy and security.

Collaborative initiatives between academia, industry, and government can accelerate the development of practical solutions. Public-private partnerships can facilitate the sharing of data, expertise, and technological resources, ultimately leading to the creation of robust AI-driven educational tools that promote sustainable learning. These collaborations should prioritise transparency and inclusivity, ensuring that the benefits of Green AI are accessible to diverse populations and educational contexts.

Cultivating a Sustainable Mindset

Beyond technological and infrastructural investments, fostering a sustainable mindset among students is the ultimate goal of integrating Green AI into education. Educational initiatives should emphasise critical thinking, ethical reasoning, and collaborative problem-solving as essential skills for addressing environmental challenges (Chapman *et al*., 2021; Taimur & Sattar, 2019). By engaging with AI-driven simulations and decision-making tools, students can develop a deeper appreciation for the interconnectedness of technological innovation and environmental stewardship.

Educators should be encouraged to adopt pedagogical strategies that promote inquiry-based learning, where students are not passive recipients of information but active participants in exploring sustainable solutions. Interdisciplinary projects, community-based learning, and real-world problem-solving exercises can all contribute to cultivating a generation that is not only knowledgeable about sustainability but also empowered to act on that knowledge.

Conclusions

The convergence of artificial intelligence, sustainability, and education represents a transformative opportunity to reshape how environmental challenges are addressed and taught. Green AI in education offers the dual promise of developing energy-efficient, responsible AI technologies and leveraging those tools to promote climate literacy, model green behaviour, and support informed environmental decision-making. This review has examined the evolution of AI in education, the principles of Green AI, and the myriad ways in which AI-driven tools can enhance sustainable learning outcomes.

By synthesising research from diverse fields, this paper has identified key areas of promise and challenge. The development of interactive platforms, virtual laboratories, and simulation environments has the potential to revolutionise climate education, while AI-based behaviour modelling and decision-making tools provide practical frameworks for understanding and addressing real-world environmental issues. At the same time, technical challenges, ethical concerns, and disparities in educational resources highlight the need for continued research, policy support, and interdisciplinary collaboration.

In conclusion, Green AI in education is not merely a technological innovation it is a paradigm shift that calls for reimagining the relationship between technology, learning, and environmental stewardship. As the global community seeks sustainable solutions to pressing environmental challenges, AI-driven educational tools can play a pivotal role in preparing future generations for the complexities of a changing world. The integration of energy-efficient, ethically designed AI into educational systems represents a critical step toward fostering a culture of sustainability that transcends disciplinary boundaries and empowers learners to make informed, responsible decisions.

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