LEVERAGING ARTIFICIAL INTELLIGENCE TO ADVANCE ENVIRONMENTAL EDUCATION FOR ALL: BUILDING A SUSTAINABLE FUTURE

ABIOLA ADIAT OMOKHABI PhD
Department of Adult Education, Faculty of Education,
University of Ibadan, Ibadan, Oyo State, Nigeria.
E-Mails: adiatomokhabi@gmail.com/aa.omokhabi@ui.edu.ng,
ORCID ID: https://orcid.org/0000-0001-5861-5065

Abstract

In the era of the 21st Century, the application of Artificial intelligence (AI) in the Environmental Education (EE) field has brought forward new opportunities in that it can further enhance education, promote sustainable behaviour, development and democratise natural information of environment on the earth. This literature review examines the opportunities AI presents for learning to develop a sustainable worldview for individual based on Transformative Learning Theory' (TLT) that emphasises critical reflection, experiential learning, and behavioural change. The article argues that in order to influence the learning significantly in regard to the environment, the individual ought to critically question his or her presuppositions, be exposed to alternative ways of thinking and take some form of action. This study examines how sustainable minds can be elevated, and critical thinking and pro-environment behaviour may potentially be fostered by AI applications such as AL-system, AI-enabled waste management, climate modeling, smart urban planning guided with TLT. These tools provide on-the-spot environmental monitoring and data-informed decision-making, as well as learning to combine the abstract and concrete. The paper concludes that the use of AI in EE offers a powerful means to advance sustainable development by enabling individuals, communities, and the world to move towards doing and being in ways that are more environmentally sustainable.

Keywords: Artificial Intelligence; Environmental Awareness; Environmental Education; Sustainable Development; Transformative Learning Theory
DOI: **https://doie.org/10.10318/SER.2026299327**

Introduction

Environmental education (EE) is a process that allows individuals to explore environmental issues, engage in problem solving, and take action to improve the environment. It is a multidisciplinary science, including aspects of biology, chemistry, physics, ecology, earth science, atmospheric science, mathematics, and geography. In some cases, it includes educating the media, public, or other target audiences in the form of printed materials, websites, media campaigns, and more. EE is education of individuals and communities for transition toward an informed society that is understanding of the environment and related issues, knowledgeable of potential solutions, and committed to becoming part of the solution. It helps people better understand the world they live in and the way they care for it to become better. Environmental education enables people to go about solving problems, investigating environmental matters, and taking steps to resolve those problems. The spirit of environmental education is inherent in the core values of education for sustainable development in educating people to take informed and responsible decisions.

The Tbilisi Conference declared environmental education a process through which a world population is made aware of and concerned about the whole environment and its related issues and has access to information, knowledge, attitudes, motivations, commitments, and skills to work either individually or collectively in finding solutions to existing problems and in the mitigation of future problems (Boca & Saraçlı, 2019). Some of the goals of environmental education are as follows: individuals are made aware of the critical environmental issues; all processes in the environment are a cause and an effect of some other process and this is emphasised; individuals are encouraged to think and process information multi-disciplinarily; the base for ecologically balanced utilisation and protection of the environment is taught; individuals are taught to use the environment economically; an ethic that prohibits environmentally destructive acts and that condemns acts which harm other people is instilled; habits of an ecological culture are taught, a willingness and ability for cooperation in the protection of the environment is cultivated, and there is an emphasis on the need to conform to ecological rules and regulations (Żeber-Dzikowska, Chmielewski, & Wojciechowska, 2016).

Environmental education should not promote a specific point of view or line of conduct. Rather, it would teach individuals how to think with different aspects of an issue through critical thinking and broaden options for problem solving and decision making (Varela Candamio, Novo-Corti, & García-Álvarez, 2018).Environmental education is being implemented in the school system from elementary education through higher education for example school environmental education, school based environmental education, on-site and by the development of learning projects; at environmental centres such as natural history museums, zoos, and so on. Outdoor education, education in the class room and education with nature are all possible. An integrated curriculum for it is designed to promote environmental awareness and sensitivity, environmental knowledge, environmental ethics, and education for sustainable development (Fang, Hassan, & LePage, 2023).

Nevertheless, there are numerous obstacles to the inclusion of EE in the school curriculum despite its acknowledged advantages at the present time. There have been considerable efforts to enhance EE in the local, regional and global scale, however there still exist barriers to the full implementation of it (Anderson & Jacobson, 2018). Several factors have been cited as contributing to the stagnation of EE, especially in public education systems (Ham, Rellergert-Taylor, & Krumpe, 1988). Following Ham, and Sewing(1988), the barriers to EE have been classified into four groups: conceptual such as uncertainties about the meaning of environmental education (EE); technical, for example constraints of time, finance and teaching materials; educational related to the teacher's level of professional knowledge and attitudinal as relating to the attitudes of trainers towards EE .Given these ongoing difficulties, there is an increasing attention towards new strategies which may provide better EE teaching and learning. A novel field of research and application is the use of artificial intelligence (AI) in education. AI is being recognised in education as a catalyst for reevaluating pedagogical approaches, curriculum design and student engagement in addition to being a technological tool. Examining how AI interacts with particular educational domains especially those addressing pressing global issues like environmental and geographical education becomes crucial as this transition takes place. AI has emerged as a promising tool that can transform EE by making learning more interactive data-driven and solution-oriented (Green & Patel, 2021).

The entire world is affected by environmental issues (Ei) not just a city or a nation. Rapid population growth has caused Ei to spread globally which has resulted in the quick and careless use of different natural resources (Abalansa, El Mahrad, Icely, &

Newton, 2021).). EE has become increasingly important as a result of the political and scientific communities increased awareness of Ei which has led to studies and projects aimed at finding solutions (Lai, 2018). Its use in EE can further increase student engagement and comprehension of ecological challenges (Brown, 2022 in Mathur & Mathur, 2025). Environmental health involves practices aimed at protecting the elements that constitute the environment in ways that safeguard human health, as well as rectifying or reducing harmful conditions that pose a threat to human health. Given the effects of environmental changes on human health, the integration of EE and health education to raise environmental awareness should be considered a fundamental necessity for individuals to maintain a healthy life (Boris, 2010 in Genc, & Kocak, 2025).

In order to improve health literacy, expand knowledge and cultivate life skills via communication health education entails creating learning opportunities. In addition to raising awareness of individual health behaviours its overarching goal is to develop the skills required to address the environmental, social and economic determinants of health and to encourage actions for bettering health outcomes. This is particularly crucial when analysing EEs contents because the two disciplines have a lot in common and share themes pertaining to both community and individual health (WHO, 2012 in Genc & Kocak, 2025). According to Ozel and Yiğit (2023) in Genc and Kocak (2025) EE provides communities and individuals with the information necessary to understand the causes and consequences of environmental issues (Ei). Its objectives are to raise awareness of Ei, foster positive behaviours toward nature and increase sensitivity. Because they both seek to address the broader determinants of health and give people the tools they need to take action for a healthier environment it is evident how health education and EE are related (Boris, 2010). Unlike traditional forms of EE, which is a comprehensive lifelong learning process that aims to develop people who are conscious of their responsibilities, investigate and identify environmental problems, participate in problem-solving processes and take effective action to improve the environment (Ural & Dadli, 2020; Samosa, Rivera, Sotto, Mazon, & Mejaro, 2022).

Conventional methods of EE however have come under criticisms for failing to successfully change individual’s perspectives and actions regarding sustainability. Digital technologies like AI have the potential to revolutionise education by addressing the flaws in conventional systems (Krstić, Aleksić, & Krstić, 2022; Kamalov, Santandreu Calonge, & Gurrib,2023; Cao & Jian ,2024; Wang,Wang,Zhu,Wang, Tran, & Du, 2024). AI also offers promising assistance in addressing challenges in EE, by facilitating personalised learning, providing better access to resources, and enhancing the effectiveness of instruction. By providing scholars with fresh viewpoints this paper aims to enhance biodiversity conservation and sustainable resource management by bridging knowledge gaps on AI integration and evaluating the value and effectiveness of AI in EE.

Literature Review

Concept of Environmental Education (EE)

EE has been seen as a vital part of modern education, encouraging environmental knowledge, attitudes, and behaviours consistent with environmental sustainability. Against the background of global environmental issues such as climate change, deforestation, loss of biodiversity, and pollution endangering ecosystems and human survival, education for enabling learners to acquire skills and competencies to deal with these issues is increasingly being emphasised. EE strives to develop environmental consciousness along with cognitive abilities and attitudes for making decisions required for sustainable lifestyles and management of natural resources (Agbor, Etan, Akuji, & Ogbor, 2025). According to Cela Sicilia and Sánchez (2015). EE is a process through which concepts are made clear and values are identified in order to acquire the skills and attitudes necessary to understand and value the relationship between human beings, culture, living things and the physical surroundings. Nikou and Economides (2017) described EE as one of the means through which individuals and society come to know the environment, engage with its animal and cultural constituents, acquire knowledge, skills, and values, and find solutions to Ei whether independently or as part of a community.de-Marcos, García-López, García-Cabot, Medina-Merodio, Domínguez, Martínez-Herráiz, and Diez-Folledo (2016) pointed out that EE is a teaching process that adds to the betterment of the environment and a process of teaching where concepts of are clarified and values are developed in addition to the necessary knowledge, skill and attitude that allows people to understand and appreciate the human-nature interactive relationship. EE can also instruct on how people could establish principles for self-behaviour and make choices in regard to environmental dilemma situations. Sheorey (2014) stated that EE intended to develop individuals in the world, observing the environment and addressing the issues, treating the environment, demonstrating problem-solving abilities on Ei and can be protected from potential issues in the future.

EE comprises numerous approaches, materials, and programmes all designed to develop and or improve environmental attitudes, values, awareness, knowledge, and skills. Its core aim is to enable individuals to take informed decisions and responsible actions for the environment (UNESCO, 1985). Ei encompassed ecological perspectives, skepticism and an understanding of complex relationships among technology and environment. Since science and technology are co-dependent and have influenced the natural environment understanding the interplay of science and technology is critical to finding solutions for contemporary Ei (Valderrama-Hernández, Alcántara, & Limón2017). Citing Vicente-Molina, Fernández-Sáinz and Izagirre-Olaizola (2013) in Ali and Arfandi (2024) EE has turned out to be a challenging field of scientific research with the increasing global concern over environmental matter. Teachers need to contribute a lot in the application of EE and face a series of barriers to communicate successfully the principles of EE. Educators are instrumental in raising community participation and knowledge of environmental concern by recruiting in preservation and environmental action group (Valderrama-Hernández, Alcántara, & Limón, 2017; Ballard Dixon & Harris ,2017). In this way, EE can fulfil its objectives, to that end, in respect of issues of personal, cognitive and emotional growth, the teacher's role as educator is fundamental when it comes to counselling and advancing the application of solutions to everyday problems.

EE mainly aims to increase public awareness of the natural processes of the environment, concentrating on how individuals are able to modify their behaviours and the ecosystems (Otto & Pensin 2017; Akinci, Yurcu, &. Kasalak, 2018). According to Ardoin and Bowers (2020) and Ardoin, Bowers and Gaillard (2020) the purpose of EE is to increase students interest through the content of environmental issues within each subject area at any education level. In line with this, EE is portrayed by Yadav et.al

(2022) as a teaching-learning process that blends human interactions with the environment and knowledge about these interactions to re-establish the waning human-environment relations and is significant in the process of enhancing sustainability, conservation and environment consciousness.

Poppe, Weigelhofer, and Winkler, (2018) define EE as a process that aims to raise people’s awareness, knowledge and skills so they can act responsibly toward the environment and make informed decisions. Uralovich, Toshmamatovich, Kubayevich, Sapaev, Saylaubaevna, Beknazarova and Khurramov, (2023) suggested that EE is a lifelong learning process that helps people develop a greater understanding and appreciation of the natural world as well as the skills and knowledge needed to make informed decisions and behave responsibly toward the environment. Llopiz-Guerra Ruiz, Hernández, Mejia, Nunayalle and Sanchez (2024) maintained that EE is an educational process that increases awareness, understanding and concern for the environment while also fostering the values and skills necessary for people to participate in problem-solving and decision-making. Operationally, EE is the process of identifying values and elucidating ideas in order to cultivate the abilities and mindsets required to comprehend and value the interconnectedness of people, cultures and the biophysical environment. EE also involves practicing, making decisions and forming one’s own behaviours regarding environmental quality issues. Thus, EE is the process that allows people to learn about the related Ei and to develop attitudes and skills related to sustainable development and resource conservation for the current generation without compromising the needs of future generations.

The United Nations Educational, Scientific and Cultural Organisation (UNESCO, 2014a), affirms that EE is essential in transmitting a conception of nature as a living system to the society and contributes in raising the public environmental awareness. UNESCO underscores the contribution of EE in protecting future global trajectories of societal quality of life (QOL) through the sense of global responsibility with respect to environment, poverty, inequalities and sustainable development. Sustainable development is meeting the needs of the present without compromising the ability of future generations to meet their own needs (Borowy, 2013).EE is crucial in this regard as it provides individuals with the necessary knowledge, attitudes and behaviours for sustainable living. EE is more than just environmental awareness, it also encourages critical thinking and the application of problem-solving tools to allow individuals to make decisions based on information concerning their environment and natural resources (UNESCO,2020).The objective of EE is to produce responsible citizens who have a comprehensive understanding of the ecological environment and its associated problems, are cognisant of available means for social and economic change that can be used to tackle these problems, and who are actively engaged in pursuing solutions. EE is also sustainable, indicating that educated leaders can rely on their gained environmental literacy to guide them in deciding and taking actions for the betterment of social, economic, and physical quality of the environment (Velempini,2025). EE benefits from traditional, place-based, and digital methods but has challenges in the areas of practice and resource equity. The use of Artificial Intelligence (AI) can assist in overcoming these gaps by delivering personalised, immersive, and data-driven learning experiences.

Theoretical Lens

Transformative Learning Theory (TLT) (Jack Mezirow, 1991)

Mezirows (1975) stated that the commencement of TLT is major life event that influence the way individuals view and make sense of their experiences. People's interpretations of life also change as they take on various perspectives. This is the essence of transformative education. Mezirow (1991) describes learning behaviour as being generated when aver problem-solving approaches. However, individual meaning perspectives colour the process of problem solving. Upon reflection on the assumptions or expectations that premise their life experiences, people will revise and adapt their perspectives of meaning when they determine that these assumptions were wrong or too narrow (Mezirow, 1991). Perspective transformation diverges from conventional learning in that it requires the development of novel frames of meaning. Reflection is the primary instrument to alter meaning perspectives. A person's external behaviour is affected by transformative learning as well as their perspectives of the world (Mezirow & Taylor, 2009).

While EE has traditionally been delivered using face-to-face modes of instruction, including outdoor field trips and school site visits, these practices do not adequately address the goals of transformative learning. Traditional methods have been known to be focused on the transmission of information and increasing awareness, as opposed to inducing deeper reflection, critical self-analysis and transformation of perspective in the learner. Barriers relating with time, finances, instructor competency, and inflexible curricula impede even more on chances for students to become involved in ongoing conversations, reflective experiences, and situational problem-solving all integral to transformative learning. Collectively, such barriers point to the importance of new pedagogies that can accommodate deeper cognitive and behavioural change. Given this setting, the incorporation of AI technology in education holds potential for becoming a key direction to enhance the educational attributes such as learner engagement, personalisation of teaching, and reflection of learning. Three dimensions of reflection were identified by Mezirow (1991) process of premise and content reflection. These two forms of content reflection and process reflection tend to alter our feelings, which in turn alters our meaning scheme. However, individual meaning perspectives will only be transformed if premise reflection occurs (Mezirow, 1998). Therefore, the application of TLT in EE is considered as a more effective method than that of traditional lecturing (Çimen & Yılmaz, 2014).

EE is intended to transform the way people think and behave in relation to the environment. AI-based technologies for intelligent tutoring systems, personalised feedback and simulations can foster critical thinking and support individuals in adopting sustainable behaviours. AI, as a subject, can receive personalised insights and environmental real-time data from AI-based systems as an agent. These technologies help individuals to see the impact of their environmental choices, and lead to more reflection on their eco-impact. An AI-powered application that models the environmental implications of everyday decisions (transportation, energy use) challenges users to question unsustainable routines and consider more sustainable options, carbon footprint trackers, pollution maps or climate modelers. This contributes to the goal of Education for All by making EE accessible to everyone. AI assist people to move from awareness to action by being a pedagogical partner and technology enabler.

AI applications for Sustainable Development, Conservation and Environmental Education

Earth Observation and Remote Sensing

Exploiting AI for monitoring satellite data, satellite imagery offers unprecedented view of Earth's surface to serve environmental monitoring programmes. Convolutional neural networks (CNNs) are also very effective in extracting important features from satellite images to precisely identify land degradation, loss of habitat and deforestation (Li, Hsu &Tsay, 2011, as cited in Islam, Ahmed, Alfify, & Riyaz, 2024). This network has been used for detection of environmental changes in a timely, AI-enabled remote sensing tools which allow monitoring of environmental indicators in near-real time. AI-technology-enabled systems are slowing detecting illegal and unsustainable practices through vegetation cover, land use changes, that can inform conservation actions (Dattamajumdar, 2021).

Sustainable Urban Development and Waste Management.

AI is an emerging technology which is becoming popular in many areas of applications especially in WM (Abdallah et al., 2020). The integration of AI and robotics in the process of designing and running urban waste treatment facilities can transform SWM by making operations more efficient and pave the way for sustainable WM (Yigitcanlar & Cugurullo 2020; Goutam Mukherjee et al., 2021). Several developed nations such as Austria, Germany, New Zealand, the United States of America, the United Kingdom, Japan, Singapore, Switzerland, South Korea, and Canada have already started leveraging AI tools in order to enhance the use of resources, efficiency, and recycling potential across the SWM process (Soni et al., 2019). WM firms increasingly rely on AI technology, particularly in the sorting and processing of solid waste (Andeobu et al., 2022; Wilts et al., 2021).

The Intelligence of Things (IoT)-Enabled SWM model with prediction, the proposed model is efficient and time saving in automation of solid waste coordination and management of overall aggregation process and in turn limits the manual intervention protean. The smart bins and the garbage level in the bins can be monitored continuously, contactless on the global platform to facilitate a sustainable throughput (Mishra et al.,2022). The application of ML Texhibits impressive properties in short-range weather forecasting (Chen, 2022). AI-based systems can also supervise the recycling procedure for unusual events, like wrong material sorting or material contamination, and notify the related staff in order to take corrective actions. (Pouyanfar et al, 2022). Moreover, artificial intelligence can help to analyse waste (Ponis et al., 2023).

AI-based methods, in particular, have found opportunities for SWM and prediction (Abbasi, & El Hanandeh, 2016; Abdallah et al., 2020). SWM is designed to improve activities such as detecting solid waste, collecting it, locating bins for SWM optimally, transporting using shortest vector, and disposing of hollow pots. Different AI, as well as hybrid models, have been developed to predict the performance of different techniques for the production, separation, storage, and treatment of solid waste (Ihsanullah et al. ,2022). Over the last years, AI has gained traction as a technique to forecast Municipal solid waste. In review of the literature several AI models has been used for prediction and classification of MSW such as artificial neural networks (ANN), support vector machine (SVM), decision trees (DT), genetic algorithms (GA), K Nearest Neighbor (kNN), and a number of other ensemble learning techniques (Wu et al., 2020).

The application of AI in waste logistics can reduce up to 36.8% of the transportation distance, resulting in cost saving of up to 13.35% and time savings of up to 28.22%. Identifying and sorting waste with an accuracy of 72.8 to 99.95% was made possible through AI. Waste pyrolysis, carbon emission evaluation, and energy conversion are significantly improved by AI and chemical analysis-based treatment of waste (Fang et al,2023). A variety of ANN methodologies that is feed-forward autoregressive, multi-layer perception (MLP), radial basis function (RBF), backpropagation (BP), and recurrent ANNs are utilised in WM (Abbasi & El Hanandeh, 2016; Ihsanullah et al., 2022). Genetic algorithms(Gas) have also found application in various WM problems, such as waste characterisation, prediction of waste generation, prediction of waste accumulation and facility location, estimation of the value of waste heating and biogas generation (Biglarijoo et al., 2017; Rabbani et al., 2018). They are also useful in reducing environmental and management costs and collection routes related to the treatment of waste (Pourreza Movahed et al., 2020).

Other popular AI model in MWM is the decision tree(DT) (Ding et al., 2023). DT is a highly accurate supervised classification approach which is capable of automatically extracting rules from unknow data (Kannangara et al., 2018). DTs have found application in MWM to estimate waste generation, waste compression, and waste sorting. They even have been applied in identifying areas of illegal waste dumping and trends in waste production (Deepnarain et al., 2019; Ding et al., 2023) .AI has emerged as a disruptive technology in the recent past and will reshape the WM process and associated challenges (Maiurova et al.,2022; Chew and others,2023 Kumari and associates,2023; Ramya and associates, 2023). WM procedures could be made more efficient in terms of productivity, the use of resources and the impact on the environment by applying the data comprehension, pattern identification, and decision-making capabilities of AIs (Huang & Koroteev 2021; Aniza et al., 2023).

The growing power and possibilities of AI are illustrated with current developments in WM applications (Yigitcanlar et al. 2020; Papagiannis and others. 2021; Di Vaio and partners. 2022; Pallathadka et al., 2023). AI is revolutionising the WM industry at many levels, from advanced sorting equipment and predictive analytics to smart waste collection solutions (Wilts et al., 2021; Bamakan et al., 2022; Zhang et al., 2022; Krishna & Sharma, 2023). One of the major trends in smart WM is the application of AI in the waste collection system. Deficiencies in traditional waste collection methods like suboptimal routing and irregular schedules are common (Cubillos, 2020). However, the AI-based systems are addressing these problems through optimisation of waste collection routes or schedules (Yadav& Karmakar 2020; Yu et al. 2021).

Smart bin systems with sensors and AI algorithms can track waste levels in real time allowing for effective resource allocation and collection scheduling (Hussain et al. in 2020). AI-powered route optimization algorithms evaluate past data traffic trends and waste production rates to identify the most effective routes for waste collection vehicles (Ghahramani et al., 2022; Lin et al., 2022) .Using the real-time information dynamic scheduling algorithms can be further optimised, thus ensuring the timeliness of the waste collection and reduction of cost. Another interesting development is the application of AI to sorting waste. Conventional methods of separating waste often require human effort and they could be time-consuming and error-prone (Das et al., 2019; Guo et al., 2021). Waste separation is increasingly becoming automated and precise enabled by AI techniques such as machine vision and image recognition (Zhang &Yan 2021; Lu ,Chen, & Xue ,2022). Advanced image recognition techniques allow for an efficient sorting of recyclables organic waste and non-recyclables through visual analysis and identify solid waste materials with high precision (Kumar et al., 2021; Majchrowska et al., 2022, Sundaralingam & Ramanathan, 2023).In addition, waste products can be effectively segregated and sorted by robotic sorting mechanisms using AI methodologies making the sorting operation easier and increasing the rate of recycling (Kumar et al, 2021).

Improving stages of the recycling cycle, AI is also playing a large role in waste recycling. Material identification and sorting using AI can enhance resource recovery and reduce waste contamination by precisely identifying different types of recyclable materials (Wu et al.,2023). Process optimisation models based on AI, analyse recycling parameter data (temperature, pressure, composition, and so on) to find the optimal operating conditions and the process efficiency. AI-based quality control and inspection systems ensure the production of high-quality recycled materials by detecting defects, contamination, and non-compliance. Moreover, robotics and automation based on AI, ease the recycling operations, reduce human error, increase throughput, and improve overall recycling effectiveness (Onoda, 2020). Waste tracking is another domain where AI is drastically advancing (Khanal et al, 2023). Real time monitoring systems, are employed to collect and analyse information on waste production, collection and disposal methods, these are enabled by IoT devices and sensor networks (Sharma et al.,2021). Once processed, these data AI algorithms can be used to streamline the WM. Waste generation trends and resources allocation to support WM practices based on data in both the historical and current situations (Soni et al., 2019a; Lu et al., 2021; Ghanbari et al., 2023; Zhu et al., 2024).

Conservation and Protection of Wildlife.

Conservation AI identifies and classifies animals, humans, and poaching equipment through the use of thermal infrared and visual spectrum cameras. The platform analyses this data using convolutional neural networks (CNNs) and transformer architectures to track species, including critically endangered ones. Real-time detection offers the immediate feedback that time-critical situations (poaching) demand, whereas non-real-time analysis enables long-term wildlife monitoring and habitat health evaluation (Fergus, Chalmers, Longmore, & Wich, 2024). Case studies from Europe, North America, Africa, and Southeast Asia exemplify the platform's achievements in species recognition, biodiversity monitoring, and poaching prevention (Fergus, et al, 2024). In the cause of prevention of extinction in endangered species, observation has to be reticent. From time to time, traditional wildlife monitoring methods can be laborious, costly, and limited in range. With the aid of GPS tracking, acoustic monitoring, and camera trap image analysis, artificial intelligence has revolutionized wildlife conservation. Poaching and illegal trade in wildlife continue to endanger species and their habitats. By recognising individuals, animals, the size of the population, and routes of migration, AI significantly contributes to conservation, providing key insights into the behaviour of species and their use of habitats (Chisom et al., 2024). To detect and disrupt illegal wildlife trade networks, AI technologies such as machine vision and natural language processing analyse vast amounts of online data. In addition, AI-enabled monitoring systems with facial recognition capabilities aid in the capture of poachers and traffickers by law enforcement, dissuading illegal activities (Nandutu, Atemkeng & Okouma, 2023).

Climate Change and Weather Prediction

AI has the capability to reshape our understanding and control of climate change (CC). AI processes and techniques are accelerating solution finding for issues with applications in understanding the drivers of CC responding to its effects and crafting responses (Carozza, & Boudreault, 2021; Cowls et al,2023). Today scientists Baji in 2028 , Reichstein, Camps-Valls, Stevens, Jung, Denzler, Carvalhais , Prabhatet , 2019 and Burr in 2019 have begun to explore the possible contributions of AI to fighting global climate change, both in terms of our scientific understanding of the causes and effects of CC and in terms of solutions development (Huntingford et al, 2019). There are many more examples of where AI and machine learning can be applied to enhance climate system modeling precision (Anderson & Lucas, 2018) to assess emissions inventories (Han, Gopal Ouyang & Key, 2021), and to enhance climate scenario projections (Nichol et al,2021) and climate impact assessments (Crane-Droesch,2018) and also to create products for low carbon technology deployment through energy, transportation and building system optimisation (Chen et al, 2021;Chen et al, 2023).

Co-integration of AI has exhibited promising results for predicting the impacts of CC (Nishant et al. 2020). In particular machine learning (ML) methods can process multi-dimensional data and identify complex patterns and associations which might be difficult to be apprehended by standard methodologies (Padhi et al., 2023). Non-linear processing of time-dependent changes, detection of weak signals, which are typically not detectable by classical climate models, can be accomplished by some ML techniques, such as neural networks (NN) or ensemble methodologies. Since AI models are capable of learning from past data and refining predictions as new data is made available, they well-suited to the evolving states of climate systems (Sri Preethaa et al.,2023). The integration of AI has demonstrated potential for enhancing the prediction of the effects of CC (Nishant et al., 2020 in Ukoba, Onisuru, Jen, Madyira & Olatunji, 2025).

For example, scientists have applied ML approaches to enhance predictions of temperature and precipitation patterns at the local to regional scales (Ahmed et al. 2020; Wang et al., 2021). Nandgude et al. (2023) reviewed the whole technological progression leading to better drought prediction, exploring the fusion of remote sensing data, meteorological observations, hydrological modeling and climate indices and demonstrating that advanced techniques (machine learning and deep learning frameworks) outperform traditional ones by enhancing the accuracy of drought prediction. According to Chen and colleagues. (2023) short-term weather prediction is the promising application of ML.

Urban Planning and Smart Cities

AI has emerged as a critical enabler in the pursuit of decarbonized and sustainable urban futures. By embedding AI into the framework of smart city (SC) development, with the end clients being urban planners and policy makers, they are, now, more than ever before, making use of tools such as ML, data analytics, predictive modelling to name but a few (Lartey & Law 2025), to enhance resource allocation and disaster and urban planning. This type of technology and data enabled more intelligent decision making thereby enhancing process efficiency and life quality in cities. (Dhayal ,Giri, Agrawal, Agrawal, Samadhiya & Kumar, 2025). Ullah et al. (2020) and Heidari et al. (2022) provide the classification results of conventional AI techniques such as ML, deep learning and reinforcement learning under the umbrella of SCs. SC and urban challenges, such as intelligent transportation systems, cybersecurity, energy-efficient smart grids, and unmanned aerial vehicles (drones), are among the high-dimensional problems that these methods are regularly and effectively applied to and used to generate optimal solutions. By implementing AI for waste segregation, traffic management, public transportation, and energy efficient building design, cities can decrease environmental pollution, reduce greenhouse gas emissions and improve the overall quality of life of urban residents (Sethy, Shaik, Saravanan & Karthika ,2024).Students can discover biodiversity, witness human impact, and participate in a variety of environmental situations via Virtual Reality (VR) and Augmented Reality (AR) applications facilitated by AI (Green & Patel, 2021). AI-based tutors can offer customized learning modules based on students' advancement, ensuring a more profound understanding of environmental topics (Kumar, 2024).

Conclusion

The promotion of EE and green development is substantially supported by AI. One leading edge way to do sustainable development for all is apply AI in EE. AI based tools such as intelligent tutoring systems (ITS) and machine learning data analytics enhance environmental literacy, promote data-driven decision making, and help community and learners live sustainably, as evidenced by research publicly available (Leal Filho et al.,2022; UNESCO 2023). Consistent with TLT, AI provides individuals on interactive, personalised, and positive learning experiences that encourage critical thinking and transformative (Mezirow, 1991). This promotes environmental stewardship at behavioural, emotional and cognitive levels.

AI applications including wildlife conservation technologies, smart city planning, remote sensing, climate prediction models, and sustainable waste management systems significantly contribute to monitoring, preserving, and restoring ecosystems. All of these have the potential to enhance environmental awareness and the development of critical environmental thinking among students. And individuals. These approaches help students and community to connect theory and practice to work towards the United Nations Sustainable Development Goals (SDGs), particularly SDG 4 (Quality Education), SDG 13 (Climate Action), and SDG 15 (Life on Land). However, the literature also highlights concerns regarding disparities in access to technology, data privacy, and the need for teacher professional development in AI-enabled instruction. The ability of AI to help drive sustainable education may well remain an unbalanced one if these voids are not addressed. To enable them to take full advantage of this potential educational institutions should foster interdisciplinary research provide equal access to the digital learning resources and integrate AI tools into teaching.

It is the responsibility of governments and lawmakers to define ethical principles and fund solutions to sustainability were based on AI. Finally and not least, to achieve the global transformative learning appropriate for sustainable development collaboration involving environmental scientists, educators and technologists. National governments must also bring their policies on sustainable education and AI-enabled EE into line at the national level to maintain coherence with international instruments such as UNESCOs Education for Sustainable Development (ESD) roadmap .Educators from preschools to universities can acquire the pedagogical skills and AI literacy needed to effectively use smart tools in education through continuing professional education .Digital infrastructure investments are critical for closing the technology divide particularly in rural and emerging areas so that inclusive and equitable access to AI-powered education can be ensured. Ethics should be developed to deal with algorithmic bias, data privacy, environmental costs of AI system, among others. Educators, AI specialists, environmental researchers, and policy makers should join forces to co-create cutting-edge context-based solutions for sustainability challenges. By integrating AI technology with transformative learning, communities can nurture responsible, intelligent, and reflective citizens who have the potential to lead collective efforts towards a sustainable and equitable future for everyone.

Suggestions

In light of the matters raised, the following suggestions would be appropriate:

1. Policy coherence and coordination: From the national level to the education institutions, AI-based environmental education methodologies must be integrated into national education and sustainability policies ensuring that learning for life is pursued.
2. Educators' Capacity Building: Curricula in teacher education and adult education must address educators' competence and confidence to ethically and effectively use AI tools for teaching and learning about the environment.
3. Equal Access to AI Technology: Special efforts should be made to deliver EE, supported by AI, to under-served and developing world communities.
4. Curriculum Design: the curriculum should incorporate the EE initiatives such as AI-supported hands-on learning techniques that promote critical thinking, problem-solving, and regional and worldwide environmental engagement.
5. Ethical, Responsible AI Use: Data privacy and transparency should continue to be monitored and applied to use of AI in EE, along with environmental responsibility.

References

Abalansa, S., El Mahrad, B., Icely, J., & Newton, A. (2021). Electronic Waste, an Environmental Problem Exported to Developing Countries: The GOOD, the BAD and the UGLY. *Sustainability*, **13** (9): 5302.

Abbasi, M., & El Hanandeh, A. (2016). Forecasting municipal solid waste generation using artificial intelligence modelling approaches. *Waste management (New York, N.Y.)*, **56**: 13–22. https://doi.org/10.1016/j.wasman.2016.05.018

Abdallah, M., Abu Talib, M., Feroz, S., Nasir, Q., Abdalla, H., & Mahfood, B. (2020). Artificial intelligence applications in solid waste management: A systematic research review. *Waste management (New York, N.Y.)*, **109**: 231–246. https://doi.org/10.1016/j.wasman.2020.04.057

Agbor, C. N., Etan, M. O., Akuji, R. T., & Ogbor, C. O. (2025). Methods of teaching environmental education for sustainability. *International Journal of Economics, Environmental Development and Society*, **6** (2): 209-233

Ahmed, K., Sachindra, D.A., Shahid, S., Iqbal, Z., Nawaz, N. & Khan, N. (2020) Multi-model ensemble predictions of precipitation and temperature using machine learning algorithms. *Atmospheric Research*, 236, Article: 104806. https://doi.org/10.1016/j.atmosres.2019.104806

Akinci, Z., Yurcu, G., & Kasalak, M. A. (2018). The Mediating Role of Perception in the Relationship between Expectation and Satisfaction in Terms of Sustainability in Tourism Education. *Sustainability*, **10** (7): 2253. https://doi.org/10.3390/su10072253

Ali, M. I., & Arfandi, A. (2024). Synchronizing Environmental Education Research Trends: Promoting Sustainable Practices and Enhancing Scientific Knowledge. *International Journal of Environment, Engineering and Education*, **6** (1): 1–11. https://doi.org/10.55151/ijeedu.v6i1.124

Andeobu, L.,Wibowo, S., & Grandhi, S. (2022). Artificial intelligence applications for sustainable solid waste management practices in Australia: A systematic review. *The Science of the total environment*, **834**: 155389. https://doi.org/10.1016/j.scitotenv.2022.155389

Anderson, C., & Jacobson, S (2018): Barriers to environmental education: How do teachers' perceptions in rural Ecuador fit into a global analysis?, *Environmental Education Research*, https://doi.org/10.1080/13504622.2018.1477120

Anderson, G. J., & Lucas, D.D. (2018). Machine learning predictions of a multiresolution climate model ensemble. *Geophysical Research Letters*, **45**: 4273–4280. https://doi.org/10.1029/2018GL077049

Aniza, R., Chen, W. H., Pétrissans, A., Hoang, A. T., Ashokkumar, V., & Pétrissans, M. (2023). A review of biowaste remediation and valorization for environmental sustainability: Artificial intelligence approach. *Environmental pollution (Barking, Essex: 1987)*, **324**: 121363. https://doi.org/10.1016/j.envpol.2023.121363

Ardoin N.M, & Bowers A.W. (2020) Early childhood environmental education: A systematic review of the research literature. *Educational Research Reviews*. **31**: 100353. doi: 10.1016/j.edurev.2020.100353.

Ardoin, N.M., Bowers, A.W. & Gaillard, E (2020). Environmental education outcomes for conservation: A systematic review, *Biological Conservation*, **241**: 108224, https://doi.org/10.1016/j.biocon.2019.108224.

Baji, T. (2018) Evolution of the GPU Device widely used in AI and Massive Parallel Processing *IEEE Electron Devices Technology and Manufacturing Conf. (EDTM) (Kobe, Japan)*

Ballard, H.L., Dixon, C.G.H. & Harris, E. M.(2017)Youth-focused citizen science: Examining the role of environmental science learning and agency for conservation, *Biological Conservation*, **208**: 65-75, https://doi.org/10.1016/j.biocon.2016.05.024.

Bamakan, S.M.H. Malekinejad, P. & Ziaeian M. (2022), Towards blockchain-based hospital waste management systems; applications and future trends *Journal of*

Cleaner Production, 349 Article 131440, https://doi.org/10.1016/j.jclepro.2022.131440.

Biglarijoo, N., Mirbagheri, S.A., Bagheri, M., & Ehteshami, M., (2017). Assessment of effective parameters in landfill leachate treatment and optimization of the process using neural network, genetic algorithm and response surface methodology. *Process safety and environmental protection*, 89–103. https://doi.org/10.1016/j.psep.2016.12.006

Boca, G. D., & Saraçlı, S. (2019). Environmental education and student's perception, for sustainability. *Sustainability*, **11** (6): 1553.

Boris, R. Y. (2010). Environmental education and health. Health Education, School and Health, **21**: 161-169.

Borowy, I. (2013). Defining sustainable development for our common future: A history of the World Commission on Environment and Development (Brundtland Commission). *Routledge*. DOIhttps://doi.org/10.4324/9780203383797 280

Brown, J. (2022). The Role of AI in Environmental Conservation. *Environmental Science Journal*, **18** (3): 45-67.

Burr, G.W. (2019). A role for analogue memory in AI hardware. *Nature Machine Intelligence,* **1**: 10–11 https://doi.org/10.1038/s42256-018-0007-y

Cao, F., & Jian, Y. (2024). The Role of integrating AI and VR in fostering environmental awareness and enhancing activism among college students. *The Science of the total environment*, **908**: 168200. https://doi.org/10.1016/j.scitotenv.2023.168200

Carozza, D.A, & Boudreault, M. (2021) A global flood risk modeling framework built with climate models and machine learning. *Journal of Advances in Modeling Earth Systems* https://doi.org/10.1029/2020MS002221

Cela, K. L., Sicilia, M. Á., & Sánchez, S. (2015). Social network analysis in e-Learning environments: A preliminary systematic review. *Educational Psychology Review*, **27** (1): 219–246. https://doi.org/10.1007/s10648-014-9276-0

Chen, C., Hu, Y., Karuppiah, M., & Kumar, P.M. (2021). Artificial intelligence on economic evaluation of energy efficiency and renewable energy technologies. *Sustainable Energy Technologies and Assessments*, **47**: : 10.1016/j.seta.2021.101358

Chen, X (2022) Machine learning approach for a circular economy with waste recycling in smart cities. *Energy Reports* **8**: 3127–3140. https://doi.org/10.1016/j.egyr.2022.01.193

Chen, L., Chen, Z., Liu, Y., Zhang, Y., Osman, A. I., Farghali, M., Hua, J., Ihara, I., Rooney, D. W., & Yap, P. S. (2023). Artificial intelligence-based solutions for climate change: a review. *Environmental Chemistry Letters*, **21** (5): 2525-2557. https://doi.org/10.1007/s10311-023-01617-y

Chen, L., Han, B., Wang, X., Zhao, J., Yang, W., & Yang, Z. (2023). Machine Learning Methods in Weather and Climate Applications: A Survey. *Applied Sciences*, **13** (21): 12019. https://doi.org/10.3390/app132112019

Chew, X., Khaw, K. W., Alnoor, A., Ferasso, M., Al Halbusi, H., & Muhsen, Y. R. (2023). Circular economy of medical waste: novel intelligent medical waste management framework based on extension linear Diophantine fuzzy FDOSM and neural network approach. *Environmental science and pollution research international*, **30** (21): 60473–60499. https://doi.org/10.1007/s11356-023-26677-z

Chisom, O.N, Biu, P.W, Umoh, A.A, Obaedo, B.O, Adegbite, A.O, & Abatan, A. (2024). Reviewing the role of AI in environmental monitoring and conservation: A data-driven revolution for our planet. *World Journal of Advanced Research and Reviews*. **21** (1): 161-71.

Çimen,O., & Yılmaz, M. (2014). The influence of transformative learning based environmental education on pre-service biology teachers' perception of environmental problems. *Bartın University Journal of Education Faculty*, **3** (1): 339–359.

Cowls, J., Tsamados, A., Taddeo, M., & Floridi, L. (2023). The AI gambit: leveraging artificial intelligence to combat climate change-opportunities, challenges, and recommendations. *AI & society*, **38** (1): 283–307. https://doi.org/10.1007/s00146-021-01294-x

Crane-Droesch, A. (2018) Machine learning methods for crop yield prediction and climate change impact assessment in agriculture. *Environmental Research Letters*, **13** (11): 114003. https://doi.org/10.1088/1748-9326/aae159

Cubillos, M. (2020). Multi-site household waste generation forecasting using a deep learning approach. *Waste management (New York, N.Y.)*, **115**: 8–14. https://doi.org/10.1016/j.wasman.2020.06.046

Das, S, Lee, S.H, Kumar, P, Kim, KiH, Lee, SSoo & Bhattacharya, S.S(2019) Solid waste management: Scope and the challenge of sustainability. *Journal of Cleaner Production*, **228**: 658-678 https://doi.org/10.1016/j.jclepro.2019.04.323

Dattamajumdar, A. (2021). An early warning AI-powered portable system to reduce workload and inspect environmental damage after natural disasters. *ArXiv, abs/2104.00876*.

de Sousa,W.G.,de Melo, E.R.P. . Bermejo, P.H.D.S., Farias R.A.S., & Gomes,A.O. (2019), How and where is artificial intelligence in the public sector going? A literature review and research agenda Government Information *Quarterly* **36** (4) Article 101392, https://doi.org/10.1016/j.giq.2019.07.00

Deepnarain, N., Nasr, M., Kumari, S., Stenstrom, ¨ T.A., Reddy, P., Pillay, K., & Bux, F. (2019). Decision tree for identification and prediction of filamentous bulking at full-scale activated sludge wastewater treatment plant. *Process Safety and Environmental Protection* **126**: 25–34. https://doi.org/10.1016/j.psep.2019.02.023.

de-Marcos, L., García-López, E., García-Cabot, A., Medina-Merodio, J. A., Domínguez, A., Martínez-Herráiz, J. J., & Diez-Folledo, T. (2016). Social network analysis of a gamified e-learning course: Small-world phenomenon and network metrics as predictors of academic performance. *Computers in Human Behavior*, **60**: 312-321. https://doi.org/10.1016/j.chb.2016.02.052

Dhayal K.S, Giri, A.K, Agrawal, R, Agrawal, S, Samadhiya, A, & Kumar, A (2025;), "Do the innovative technological advancements foster the green transition pathways for industry 5.0? A perspective toward carbon neutrality". Benchmarking: *An International Journal*,. https://doi.org/10.1108/BIJ-04-2024-0330

Di Vaio, A., Hassan, R., D'Amore, G. & Dello Strologo A. (2022), Digital technologies for sustainable waste management on-board ships: An analysis of best practices from the cruise industry IEEE Transactions on Engineering Management, **71**: 12715-12728 doi = 10.1109/TEM.2022.3197241

Ding, X., Feng, C., Yu, P., Li, K., & Chen, X., (2023). Gradient boosting decision tree in the prediction of emission of waste incineration. Energy, **264**: 126174. https://doi.org/ 10.1016/j.energy.2022.126174

Fang, B., Yu, J., Chen, Z., Osman, A.I, Farghali, M, Ihara, I, Hamza, E.H, Rooney, D.W, & Yap, P.S. (2023). Artificial intelligence for waste management in smart cities: a review. *Environmental Chemistry Letters*. May 9: 1-31. doi: 10.1007/s10311-023-01604-3. Epub ahead of print. PMID: 37362015; PMCID: PMC10169138.

Fang, W.T., Hassan, A., & LePage, B.A. (2023). Introduction to Environmental Education. In: The Living Environmental Education. *Sustainable Development Goals Series*. Springer, Singapore. https://doi.org/10.1007/978-981-19-4234-1_1

Fergus, P., Chalmers, C., Longmore, S., & Wich, S. (2024). Harnessing Artificial Intelligence for Wildlife Conservation. *Conservation*, **4** (4): 685-702. https://doi.org/10.3390/conservation4040041

Genc, H. N. & Kocak, N. (2025). Bibliometric analysis of studies on artificial intelligence in environmental and health education. *Journal of Education in Science, Environment and Health* **11** (2): 140-150. https://doi.org/10.55549/jeseh.806

Ghahramani, M., Zhou, M., Molter, A. & Pilla, F. (2022) Iot-Based Route Recommendation for an Intelligent Waste Management System. *IEEE Internet of Things Journal*, **9**: 11883-11892.https://doi.org/10.1109/jiot.2021.3132126

Ghanbari, F.. Kamalan, H & Sarraf A. (2023). Predicting solid waste generation based on the ensemble artificial intelligence models under uncertainty analysis *Journal of Material Cycles and Waste Management* **25**: 920-930, https://doi.org/10.1007/s10163-023-01589-9

Goutam Mukherjee, A., Ramesh Wanjari, U., Chakraborty, R., Renu, K., Vellingiri, B., George, A., C R, S. R., & Valsala Gopalakrishnan, A. (2021). A review on modern and smart technologies for efficient waste disposal and management. *Journal of environmental management*, **297**: 113347. https://doi.org/10.1016/j.jenvman.2021.113347.

Green, R., & Patel, S. (2021). AI in Education: Enhancing Learning Through Technology. *Journal of Educational Research*, **12** (4): 78-92.

Guo, H. N., Wu, S. B., Tian, Y. J., Zhang, J., & Liu, H. T. (2021). Application of machine learning methods for the prediction of organic solid waste treatment and recycling processes: A review. *Bioresource technology*, **319**: 124114. https://doi.org/10.1016/j.biortech.2020.124114

Ham, S. H., Rellergert-Taylor, M. H., & Krumpe, E. E. (1988). Reducing barriers to environmental education. *The Journal of Environmental Education*, **19** (2): 25-33. https://www.researchgate.net/publication/241739390_Reducing_Barriers_to_Environmental_Education

Ham, S.H., & Sewing, D. (1988). Barriers to Environmental Education. *The Journal of Environmental Education*, **19**: 17-24.

Han, Y., Gopal, A., Ouyang, L., & Key, A. (2021). Estimation of Corporate Greenhouse Gas Emissions via Machine Learning. *ArXiv, abs/2109.04318*.

Heidari, A., Navimipour, N. J., & Unal, M. (2022). Applications of ML/DL in the management of smart cities and societies based on new trends in information technologies: A systematic literature review. *Sustainable Cities and Society* (85). https://doi.org/10.1016/j.scs.2022.104089

Huang, J. & Koroteev, D. D. (2021)Artificial intelligence for planning of energy and waste management *Sustainable Energy Technologies and Assessment* , 47 Article 101426, https://doi.org/10.1016/j.seta.2021.101426.

Huntingford, C., Jeffers, E. S., Bonsall, M. B., Christensen, H. M., Lees, T., & Yang, H. (2019). Machine learning and artificial intelligence to aid climate change research and preparedness. *Environmental Research Letters*, **14** (12): https://doi.org/10.1088/1748-9326/ab4e55

Ihsanullah, I. Alam, G. Jamal, A. & Shaik F. (2022), Recent advances in applications of artificial intelligence in solid waste management: a review Chemosphere, 309 Article 136631, 10.1016/j.chemosphere.2022.136631

Islam, Z., Ahmed, A., Alfify, M.H., & Riyaz, N (2024). The Impact Of Artificial Intelligence On Environment And Sustainable Development In India, *Educational Administration: Theory and Practice*, **30** (5): 1850-1856 Doi: 10.53555/kuey.v30i5.3196

Kamalov, F., Santandreu Calonge, D., & Gurrib, I. (2023). New era of artificial intelligence in education: towards a sustainable multifaceted revolution. *Sustainability*, **15** (16): 12451. https://doi.org/10.3390/su15161245

Kannangara, M., Dua, R., Ahmadi, L., & Bensebaa, F., (2018). Modeling and prediction of regional municipal solid waste generation and diversion in Canada using machine learning approaches. *Waste Management*, **74**: 3–15. https://doi.org/10.1016/j. wasman.2017.11.057

Khanal, S. K., Tarafdar, A., & You, S. (2023). Artificial intelligence and machine learning for smart bioprocesses. *Bioresource technology*, **375**: 128826. https://doi.org/10.1016/j.biortech.2023.128826

Krishna, G., & Sharma, A. (2023). A Fuzzy Logical based Artificial Intelligence Method for Designed to Effectively Predict and Manage the Solid Waste. *2023 IEEE International Conference on Integrated Circuits and Communication Systems (ICICACS)*, 1-6.

Krstić, L., Aleksić, V., & Krstić, M. (2022). Artificial Intelligence in Education: A Review. *Proceedings TIE 2022*. 223–228. https://doi.org/10.46793/TIE22.223K

Kumar, A. (2024). AI-Powered Learning: The Future of Environmental Education. *AI and Society*, 29(1), 112-135.

Kumar, N.M. Mohammed, M.A. Abdulkareem, K.H. Damasevicius, R. Mostafa, S.A., Maashi, M.S. & Chopra, S.S. (2021). Artificial intelligence-based solution for sorting COVID related medical waste streams and supporting data-driven decisions for smart circular economy practice *Process Safety and Environmental Protection*, **152**: 482-494, https://doi.org/10.1016/j.psep.2021.06.026.

Lartey, D. & Law, K. M. Y. (2025). Artificial intelligence adoption in urban planning governance: A systematic review of advancements in decision-making, and policy making. *Landscape Urban Planing*. **258**: 105337. https://doi.org/10.1016/j.landurbplan.2025.105337

Lai, C. (2018). A study of fifth graders' environmental learning outcomes in Taipei. *International Journal of Research in Education and Science*, **4** (1): 252-262. DOI:10.21890/ijres.383171

Leal Filho, W., Wall, T., Rui Mucova, S.A., Nagy, G.J., Balogun, A.-L., Luetz, J.M., Ng, A.W., Kovaleva, M., Safiul Azam, F.M., Alves, F., Guevara, Z., Matandirotya, N.R., Skouloudis, A., Tzachor, A., Malakar, K., & Gandhi, O. (2022). Deploying artificial intelligence for climate change adaptation, in

Technological Forecasting and Social Change, *Elsevier*, **180**: 121662, https://doi.org/10.1016/j.techfore.2022.121662.

Li , C., N.C. Hsu, & S.-C. Tsay (2011), A study on the potential applications of satellite data in air quality monitoring and forecasting, *Atmospheric Environment.*, **45**: 3663-3675, doi:10.1016/j.atmosenv.2011.04.032.

Lin, K. Zhao, Y. Kuo, J.H. Deng, H. Cui, F. Zhang, Z Zhang, M Zhao, C Gao, X ., Zhou, T & Wang,T (2022), Toward smarter management and recovery of municipal solid waste: A critical review on deep learning approaches *Journal of Cleaner Production*, **346** Article 130943, https://doi.org/10.1016/j.jclepro.2022.130943

Lin, K. Zhao, Y. & Kuo J.-H. (2022), Deep learning hybrid predictions for the amount of municipal solid waste: a case study in Shanghai Chemosphere, 307 Part 4, 136119, https://doi.org/10.1016/j.chemosphere.2022.136119

Llopiz-Guerra, K, Ruiz ,D.U , Hernández, R.M., Mejia,V.L,V., Nunayalle ,J,,D-R., J., & Sanchez,K.R (2024) Importance of Environmental Education in the Context of Natural Sustainability. *Natural and Engineering Sciences*, **9** (1): 57-71 doi: 10.28978/nesciences.1473461

Lu, W., Chen, J., & Xue, F. (2022). Using computer vision to recognize composition of construction waste mixtures: a semantic segmentation approach. *Resources, Conservation & Recycling*, **178**: 106022. Doi: 10.1016/j.resconrec.2021.106022

Maiurova, A., Kurniawan, T., Kustikova, M., Bykovskaia, E., Othman, M.H., Singh, D., & Goh, H.H. (2022). Promoting digital transformation in waste collection service and recycling in Moscow (Russia): Applying a circular economy paradigm to mitigate climate change impacts on the environment. *Journal of Cleaner Production*.

Majchrowska, S., Mikołajczyk, A., Ferlin, M., Klawikowska, Z., Plantykow, M. A., Kwasigroch, A., & Majek, K. (2022). Deep learning-based waste detection in natural and urban environments. *Waste management (New York, N.Y.)*, **138**: 274–284. https://doi.org/10.1016/j.wasman.2021.12.001

Mathur, P. & Mathur, R (2025) Artificial Intelligence and Its Role In Environmental Education in Jodhpur *International Journal of Novel Research and Development*, **10** (5): 2456-4184 | IJNRD.ORG

Mezirow, J. (1991). Transformative Dimensions of Adult Learning. San Francisco: Jossey-Bass.

Mezirow, J. (1975). Education for perspective transformation: Women's reentry programs in community colleges. New York: Columbia University

Mezirow, J., & Taylor, E. W. (2009). Transformative Learning in Practice. Insights from Community, Workplace and Higher Education. San Francisco, CA: Jossey-Bass.

Mezirow, J. (1998). On critical reflection. *Adult Education Quarterly*, **48**: 185-198. http://dx.doi.org/10.1177/074171369804800305

Mishra, S., Jena, L., Tripathy, H., & Gaber, T. (2022). Prioritized and predictive intelligence of things enabled waste management model in smart and sustainable environment. *Plos One*, **17** (8): e0272383. https://doi.org/10.1371/journal.pone.0272383

Nandgude, N., Singh, T. P., Nandgude, S., & Tiwari, M. (2023). Drought Prediction: A Comprehensive Review of Different Drought Prediction Models and Adopted Technologies. *Sustainability*, **15** (15): 11684. https://doi.org/10.3390/su151511684

Nandutu I, Atemkeng M, & Okouma P. (2023) Integrating AI ethics in wildlife conservation AI systems in South Africa: A review, challenges, and future research agenda. *AI and Society* **38** (1): 245-257

Nichol, J. J, Peterson, M. G., Peterson, K.J., Fricke, G. M, & Moses, M. E. (2021). Machine learning feature analysis illuminates disparity between E3SM climate models and observed climate change. *Journal of Computational and Applied Mathematics*, 395. https://doi.org/10.1016/j.cam.2021.113451

Nikou, S. A., & Economides, A. A. (2017). Mobile-based assessment: Investigating the factors that influence behavioral intention to use. *Computers & Education*, **109**: 56–73. https://doi.org/10.1016/j.compedu.2017.02.005

Nishant R, Kennedy M, & Corbett J (2020) Artificial intelligence for sustainability: challenges, opportunities, and a research agenda. *International Journal of Information Management*, **53**: 102104. https://doi.org/10.1016/J.IJINFOMGT.2020.102104

Onoda, H. (2020). Smart approaches to waste management for post-COVID-19 smart cities in Japan. *IET Smart Cities*, **2** (2): 89-94. https://doi.org/10.1049/iet-smc.2020.0051

Otto, S., & Pensini, P. (2017). Nature-based environmental education of children: Environmental knowledge and connectedness to nature, together, are related to ecological behaviour. *Global Environmental Change*, **47**: 88–94. https://doi.org/10.1016/j.gloenvcha.2017.09.009

Padhi, A., Agarwal, A., Saxena, S. K., & Katoch, C. D. S. (2023). Transforming clinical virology with AI, machine learning and deep learning: a comprehensive review and outlook. *Virusdisease*, **34** (3): 345–355. https://doi.org/10.1007/s13337-023-00841-y

Pallathadka, H., Mustafa, M., Sanchez, D.T., Sekhar Sajja, G., Gour, S., & Naved, M. (2023). Impact of Machine learning on Management, Healhcare and Agriculture. Materials Today: Proceedings, SI:5 **80**: 2803–2806. DOI: 10.1016/j.matpr.2021.07.042.

Papagiannis, F., Gazzola, P., Burak, O., & Pokutsa, I. (2021). A European household waste management approach: Intelligently clean Ukraine. *Journal of environmental management*, **294**: 113015. https://doi.org/10.1016/j.jenvman.2021.113015

Ponis, S., Plakas, G, Aretoulaki ,E., Tzanetou D, & Maroutas,T.N (2023) LoRaWAN for tracking inland routes of plastic waste: introducing the smart TRACKPLAST bottle. *Cleaner Waste Systems* 4:100068. https://doi.org/10.1016/j.clwas.2022.100068

Poppe, M., Weigelhofer, G., & Winkler, G. (2018). Public Participation and Environmental Education. In: Schmutz, S., Sendzimir, J. (eds) Riverine Ecosystem Management. Aquatic Ecology Series, 8. Springer, Cham. https://doi.org/10.1007/978-3-319-73250-3_22

Pourreza Movahed, Z., Kabiri, M., Ranjbar, S. & Joda, F., (2020). Multi-objective optimization of life cycle assessment of integrated waste management based on genetic algorithms: a case study of Tehran. *Journal of Cleaner Production*, **247**: 119153. https://doi. org/10.1016/j.jclepro.2019.119153

Pouyanfar, N, Harofte S.Z, Soltani M, Siavashy, S., Asadian, E., Ghorbani-Bidkorbeh, F., Keçili R, & Hussain, C.M (2022) Artificial intelligence-based microfluidic platforms for the sensitive detection of environmental pollutants: recent advances and prospects. *Trends in Environmental Analytical Chemistry*, **34**: e00160. https://doi.org/10.1016/j.teac.2022.e00160

Rabbani, M., Heidari, R., Farrokhi-Asl, H., & Rahimi, N., (2018). Using metaheuristic algorithms to solve a multi-objective industrial hazardous waste location-routing problem considering incompatible waste types. *Journal of Cleaner Production*, **170**: 227–241. https://doi.org/10.1016/j.jclepro.2017.09.029

Ramya, P., Ramya, V., & Markapudi, B. R. (2023). E-waste management using hybrid optimization-enabled deep learning in iot-cloud platform. *Advances in Engineering Software*, **176**: 103353. https://doi.org/10.1016/j.advengsoft.2022.103353

Reichstein, M., Camps-Valls, G., Stevens, B., Jung, M, Denzler, J., Carvalhais, N. & Prabhatet (2019). Deep learning and process understanding for data-driven Earth system science. *Nature*, **566**: 195–204 https://doi.org/10.1038/s41586-019-0912-1

Samosa, R. C., Rivera, M. S. M., Sotto, M. F. L. R., Mazon, E. A. B., & Mejaro, K. A. S. (2022). Pre-service teachers' environmental awareness, attitude, and practices: Input for ecological capacity building programs. *European Journal of Innovation in Non formal Education*, **2** (7): 17–30. https://inovatus.es/index.php/ejine/article/view/1079

Sethy, A., Shaik, N., Saravanan, V. & Karthika, S. (2024). 10 The future with AI and AI in action. In V. de Albuquerque, P. Raj & S. Yadav (Ed.), *Toward Artificial General*

Sharma, H., Haque, A., & Blaabjerg, F. (2021). Machine Learning in Wireless Sensor Networks for Smart Cities: A Survey. *Electronics*, **10** (9): 1012. https://doi.org/10.3390/electronics10091012

Sheorey, T. (2014). Empirical evidence of relationship between virtual lab development and students learning through field trials on vlab on mechatronics. *International Journal of Information and Education Technology*, **4** (1): 97-102 https://doi.org/10.7763/IJIET.2014.V4.377

Soni, U, Roy, A., Verma A., & Jain, V. (2019) Forecasting municipal solid waste generation using artificial intelligence models—a case study in India. *SN Applied Sciences*, **1**: 162. https://doi.org/10.1007/s42452-018-0157-x

Sri Preethaa, K. R., Muthuramalingam, A., Natarajan, Y., Wadhwa, G., & Ali, A. A. Y. (2023). A Comprehensive Review on Machine Learning Techniques for Forecasting Wind Flow Pattern. *Sustainability*, **15** (17): 12914. https://doi.org/10.3390/su15171291

Sundaralingam, S., & Ramanathan, N. (2023). A Deep Learning-Based approach to Segregate Solid Waste Generated in Residential Areas. *Engineering, Technology & Applied Science Research*, **13** (2): 10439–10446. https://doi.org/10.48084/etasr.5716

Ukoba, K., Onisuru, O.R., Jen, T.C, Madyira, D.M, & Olatunji, K.O. (2025). Predictive modeling of climate change impacts using Artificial Intelligence: a review for equitable governance and sustainable outcome. *Environmental Science Pollution and Research*, **32** (17): 10705–10724 https://doi.org/10.1007/s11356-025-36356-w

Ullah, Z., Al-Turjman, F., Mostarda, L., & Gagliardi, R. (2020). Applications of Artificial Intelligence and Machine Learning in Smart Cities. *Computer Communications*, **154** (313–323). https://doi.org/10.1016/j.comcom.2020.02.069

UNESCO (2014). Education for Sustainable Development: Roadmap for Implementing the Global Action Programme on ESD.

UNESCO. (2020). Education for Sustainable Development: A roadmap. https://doi.org/10.54675/YFRE1448 66

UNESCO—UNEP, (1985). International Environmental Education Programme, Series 17. A Comparative Survey of the Incorporation of EE into School Curricula." Unesco Paris, France

Ural, E. & Dadli, G. (2020). The effect of problem-based learning on 7th-grade students' environmental knowledge, attitudes, and reflective thinking skills in environmental education. *Journal of Education in Science, Environment and Health*, **6** (3): 177192.DOI:10.21891/jeseh.705145

Uralovich, K. S., Toshmamatovich, T. U., Kubayevich, K. F., Sapaev, I., Saylaubaevna, S. S. , Beknazarova, Z. & Khurramov, A. (2023). A primary factor in sustainable development and environmental sustainability is environmental education. *Caspian Journal of Environmental Sciences*, **21** (4): 965-975. doi: 10.22124/cjes.2023.7155

Valderrama-Hernández, R Alcántara, L. & Limón, D. (2017) The Complexity of Environmental Education: Teaching Ideas and Strategies from Teachers, *Procedia - Social and Behavioral Sciences,* **237**: 968-974, https://doi.org/10.1016/j.sbspro.2017.02.137

Varela-Candamio, L., Novo-Corti, I., & García-Álvarez, M. T. (2018). The importance of environmental education in the determinants of green behavior: A meta-analysis approach. *Journal of Cleaner Production*, **170**: 1565-1578.

Velempini, K. (2025). Assessing the Role of Environmental Education Practices Towards the Attainment of the 2030 Sustainable Development Goals. *Sustainability*, **17** (5): 2043. https://doi.org/10.3390/su17052043

Vicente-Molina, M.A., Fernández-Sáinz, A., & Izagirre-Olaizola, J. (2013). Environmental knowledge and other variables affecting pro-environmental behaviour: comparison of university students from emerging and advanced countries. *Journal of Cleaner Production,* **61**: 130–138. https://doi.org/10.1016/j.jclepro.2013.05.015.

Wang, F., Tian, D., Lowe, L., Kalin, L., & Lehrter, J. (2021). Deep learning for daily precipitation and temperature downscaling. *Water Resources Research*, **57**: e2020WR029308. https://doi. org/10.1029/2020WR029308

Wang, S., Wang, F., Zhu, Z., Wang, J., Tran, T., & Du, Z. (2024). Artificial Intelligence in Education: A Systematic Literature Review. *Expert Systems with Applications*, **252**: Article 124167.https://doi.org/10.1016/j.eswa.2024.12416

Wilts, H, Garcia, B.R, Garlito R.G, Gómez, L.S, & Prieto, E.G (2021). Artificial intelligence in the sorting of municipal waste as an enabler of the circular economy. *Resources*, **10**: 28. https://doi.org/10.3390/resources10040028

World Health Organisation. (2012). Health education: theoretical concepts, effective strategies, and core competencies. A foundation document to guide capacity development of health educators (p.13). Cairo: Egypt: WHO Regional Office for the Eastern Medittenan https://applications.emro.who.int/dsaf/emrpub_2012_en_1362.pdf

Wu, T.-W. Zhang H. , Peng, W., Lü, F. & He P.-J. (2023), Applications of convolutional neural networks for intelligent waste identification and recycling: *Resources, Conservation and Recycling*, **190**: 106813, https://doi.org/10.1016/j.resconrec.2022.106813.

Yadav, V. & Karmakar, S. (2020) Sustainable collection and transportation of municipal solid waste in urban centers Sustainable Cities and Society., **53** Article 101937, https://doi.org/10.1016/j.scs.2019.101937.

Yigitcanlar, T., & Cugurullo, F. (2020) The sustainability of srtificial intelligence: an urbanistic viewpoint from the lens of smart and sustainable cities. Sustainability **12**: 8548. https://doi.org/10.3390/su12208548Return to ref 2020 in article

Yu, K. H., Zhang, Y., Li, D., Montenegro-Marin, C. E., & Kumar, P. M. (2021). Environmental Planning Based on Reduce, Reuse, Recycle and Recover Using Artificial Intelligence. *Environmental Impact Assessment Review*, **86**: 106492. https://doi.org/10.1016/j.eiar.2020.106492

Żeber-Dzikowska, I., Chmielewski, J., & Wojciechowska, M. (2016). Ecological and environmental education in the ethical context. *Environmental Protection and Natural resource*s, **27**: 29 68), 44-47. DOI 10.1515 /OSZN-2016-0011

Zhang, C., Dong, H., Geng, Y., Liang, H., & Liu, X. (2022). Machine learning based prediction for China's municipal solid waste under the shared socioeconomic pathways. *Journal of environmental management*, **312**: 114918. https://doi.org/10.1016/j.jenvman.2022.114918

Zhang, M. & Yan, J. (2021), A data-driven method for optimizing the energy consumption of industrial robots *Journal of Cleaner Production*, **285** Article 124862 https://doi.org/10.1016/j.jclepro.2020.124862.

Zhu, L., Tian, Z., & Du, J. (2024). Spatial-temporal redundancy evaluation of the municipal solid waste incineration treatment capacity: the case study of China. *Environmental science and pollution research international*, **31** (7): 9948–9963. https://doi.org/10.1007/s11356-023-26989-0