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Green Technology In Education. A Comparative Review Of Sub-Saharan Africa With Insights From India's Experience

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Abstract
Sub-Saharan Africa faces the dual challenges of expanding educational access and addressing pressing environmental concerns, including the growing problem of electronic waste. This literature-based study investigates the intersection of these challenges by exploring how green technology, specifically virtual field trips, electronic waste (e-waste) recycling, and digital textbooks, can enhance educational equity while promoting environmental sustainability. This chapter will uncover how these technologies function as integrative solutions within the region's resource-constrained educational environments.
A thematic literature review approach was employed to synthesize academic publications, grey literature, and program evaluations focused on green technologies in education across Sub-Saharan Africa (SSA). The sources were examined to identify recurring themes, advantages, and implementation-related challenges. Technology accessibility, infrastructure constraints, and the influence of institutional and policy support on results were given special consideration. This chapter provides insights into the challenges and complexities of embracing such technologies in a large and diverse nation such as India, concluding India's experience in integrating green technology into education. It lists effective practices and emphasizes the main difficulties encountered when incorporating green technologies into the classroom. The chapter contributes theoretically by framing green educational technologies, including virtual field trips, digital textbooks, and e-waste recycling initiatives, as dual-function tools for socio-environmental transformation. From a policy perspective, it reveals a gap in strategic frameworks that integrate educational innovation with environmental management. According to the study's findings, scalable initiatives that promote the full utilization of digital textbooks, install e-waste recycling facilities in schools, and incorporate virtual field trips into school curricula can help close experiential learning gaps, while also supporting strategies for achieving sustainability and educational parity. To fully realise the promise of green technology in education, multi-sectoral cooperation, improved policy coherence, and longitudinal research may be recommended.
Keywords: *Green technology, virtual field trips, e-waste recycling, digital textbooks, sub-Saharan Africa, educational equity, and environmental sustainability.*

INTRODUCTION

Sustainable development in education has become a priority as communities worldwide face environmental challenges and resource constraints (Abo-Khalil, 2024). To enhance teaching and learning, green education technology incorporates environmentally sustainable innovations and practices such as renewable energy, digital resources, and waste reduction strategies in regions such as (SSA), where educational needs are high (Moner-Girona et al., 2025). Infrastructure is often limited, and leveraging green technology can address multiple goals: expanding access to quality education, reducing environmental impacts, and fostering environmental stewardship among learners (Arzo & Hong, 2024). Simultaneously, emerging economies such as India have been implementing large-scale educational technology initiatives that offer lessons in sustainability and scalability (Niederhauser et al., 2018). India's experiences, from digital textbook platforms to electronic waste (e-waste) policies, offer valuable insights for SSA countries seeking to integrate green technology into their education (Grandhi et al., 2024).
Global frameworks such as the U.N. Sustainable Development Goals (SDGs) emphasize both Quality Education (SDG 4) and Climate Action (SDG 13), highlighting that education systems must innovate to be inclusive and environmentally sustainable (Barnty & Barnabas, 2024). The three critical areas where education and environmental sustainability intersect are digital textbooks, virtual learning resources, and the proper disposal of electronic waste (e-waste) (Jain et al., 2023). Virtual solutions, such as online labs or virtual field trips, can broaden students' horizons and potentially reduce carbon footprints by eliminating the need for actual travel and reducing infrastructure requirements (Schott, 2017). Similarly,

managing e-waste in educational institutions through recycling initiatives or public awareness campaigns reduces pollution and provides an example of responsible consumption (related to SDG 12: Responsible Consumption and Production) (Apprey et al., 2024). Utilizing digital textbooks effectively and sustainably can eventually reduce expenses and paper usage, thereby improving educational accessibility and positively impacting the environment (Alam et al., 2023).
This paper provides an introduction and literature review on how green technology is being leveraged in education in sub-Saharan Africa, focusing on three domains: (1) virtual field trips, (2) e-waste recycling, and (3) digital textbooks. We draw on empirical studies and examples from various Sub-Saharan African (SSA) countries to illustrate the current practices, benefits, and challenges in the region. In each domain, we also incorporated comparative insights from India, a country with large-scale educational technology deployments, to understand how India's experience can inform and support sustainable educational practices in SSA.

Research Questions

1. How can green technologies, specifically virtual field trips, e-waste recycling, and digital textbooks, enhance educational equity in Sub-Saharan Africa?
2. In what ways do these technologies contribute to environmental sustainability in resource-constrained educational environments?
3. What inferences can be drawn from India's experience by integrating green technology into education that can help shape policies and practices in Sub-Saharan Africa?

METHODOLOGY

This study employed a thematic literature review to investigate how green technologies, specifically virtual field trips, e-waste recycling, and digital textbooks, can simultaneously enhance educational equity and promote environmental sustainability in sub-Saharan Africa. The review synthesized information from a wide range of sources, including academic databases such as Scopus, Web of Science, ScienceDirect, and Google Scholar, as well as gray literature from institutions such as UNESCO. These sources were selected because they offer comparative perspectives from India and are relevant to the integration of green technologies in educational settings with limited resources in sub-Saharan Africa.
This study focused on identifying recurring themes, including the benefits of academic innovation for the environment, infrastructure and connectivity constraints, institutional and regulatory support, and technological accessibility to demonstrate effective tactics and significant barriers to the adoption of green educational technologies. The experience of India was used as a comparative case study. Thematic patterns were obtained from literature to understand the socio-environmental impacts of these tools. While offering valuable insights, this study acknowledges certain limitations, including the uneven availability of up-to-date data and scarcity of longitudinal assessments in some regions.

Virtual Field Trips

Virtual field trips are technology-mediated experiences that enable students to explore distant or inaccessible places through digital simulations such as virtual reality (VR) or interactive online tours (Han, 2020). Virtual field trips use multimedia, 360° imageries, or VR headsets to create immersive learning environments (Heuke et al., 2023). This method is relevant to sustainable education in two ways. Pedagogically, it enhances learning by introducing real-world situations into the classroom (Brundiers et al., 2010). This reduces the need for logistics and transportation associated with conventional field trips, which benefits the environment (Putz et al., 2018). Virtual journeys reduce fuel consumption and carbon emissions by eliminating the need for buses or aeroplanes for educational excursions, thus aligning with eco-friendly practices. They may also be less expensive and safer for schools in remote or conflict-affected areas, where a field trip is not feasible (Javaid et al., 2024).
Research supports the educational benefits of field trips. For example, Markowitz et al. (2018) tested immersive VR field trips as a medium for teaching climate change concepts to over 270 participants. Across controlled experiments and field studies, researchers found that students who experienced an immersive underwater world, showcasing the effects of ocean acidification, demonstrated significant knowledge gains and even more positive post-intervention environmental attitudes (Borda Ann, 2023). As learners explore the virtual environment, their understanding of ocean chemistry and ecological

impacts has become increasingly significant (Markowitz et al., 2018). This evidence suggests that well-designed virtual experiences can deepen comprehension of complex scientific issues and motivate pro-environmental behavior, which is highly desirable in sustainability education (Douglas et al., 2024). VR field trips thus offer a way to engage students with topics such as climate change, wildlife conservation, or geography in a memorable and impactful manner that traditional lectures may not achieve (Alqudah et al., 2023).

Virtual Field Trips in Sub-Saharan Africa

In sub-Saharan Africa, virtual field trips have emerged as innovative solutions to longstanding educational gaps (Chimbunde & Jakachira, 2024). Many schools in rural or under resourced communities cannot afford to take students on frequent field trips to museums, historical sites, or natural landmarks (Mujtaba et al., 2018). Infrastructure challenges and budget constraints mean that students may finish primary school without visiting notable sites in their country (Nherera & Mukora, 2024). Virtual reality technology helps bridge this gap. One notable example comes from Zimbabwe, where a local ed-tech startup created FundoVR, a platform for low-cost virtual excursions (Nkosana,2019). Teachers and students provided positive feedback on the pilot testing, which prompted the project to grow (Heuke et al., 2023). Thousands of learners have since been able to virtually "visit" important cultural and environmental sites, enriching their learning without travel costs and logistical hurdles (Vinnakota et al., 2023).

In Kenya, social enterprises utilize virtual reality (VR) for educational enrichment and environmental awareness (Silaji & Masudi, 2024). At Mcedo Beijing School in Nairobi's Mathare informal settlement, students use VR headsets for virtual field trips that complement their lessons (Opali,2023) . One module virtually transports pupils to scenes illustrating plastic pollution, such as marine life affected by plastic waste and interactive scenarios on waste collection and sorting (Kumar et al., 2021) . Organizers note that it is difficult for children to grasp abstract topics, such as pollution or climate change, when they are only taught the theory, but seeing the impacts in a virtual world makes the lessons more concrete (Kiyuka et al., 2024). Indeed, students have been learning about the importance of separating garbage and the downstream effects of littering through these virtual reality (VR) experiences (Guinong & Leong, 2024). Beyond individual startups, governments and international partners in Africa are also taking notes (Mkwizu,2022). The African Union has showcased VR education innovations, and countries like South Africa are exploring similar tools through pilot programs and NGO initiatives, such as virtual Safari experiences for science classes (Shambare,2025). In Zimbabwe and Kenya, the success of early adopters demonstrates the feasibility of virtual reality (VR) (Mutabari,2024). Even in low-income settings, relatively affordable VR kits, often consisting of a smartphone-based VR headset and local 360° videos, can make a significant difference (Papachristos, 2017). Challenges remain, including equipment cost, teacher training, and reliable electricity; however, momentum is building. By utilizing virtual field trips, SSA schools find greener ways to offer experiential learning, reducing the need for fuel-consuming travel while broadening student horizons (Schott, 2017)

Virtual Field Trips: Insights from India

Although on a smaller scale than in other wealthy countries, virtual and augmented reality are slowly turning into educational settings in India (Kamiń´ska et al., 2023). With numerous schools and students, the Indian educational system has recognized the potential of virtual reality (VR) to enhance learning in disciplines such as geography, science, and history (Roy, 2024). VR modules have been implemented in classrooms through several private projects and pilot programmes (Yildirim et al., 2020). For example, some progressive schools, especially in urban areas, have established virtual reality (VR) labs where students can take virtual tours of historical monuments, explore the solar system, or delve into ocean ecosystems as part of their curricula (Analyti et al., 2024). The central government's policies encourage digital innovation. India's National Education Policy 2020 explicitly calls for the integration of educational technology and mentions emerging tools, including AR/VR, to improve teaching outcomes and equity (Singh, 2023). VR in Indian public schools is still in its infancy as of the mid-2020s but is frequently promoted by startups or state governments collaborating with educational institutions (Roy, 2024).

Another insight is scalability: India's sheer scale implies that any successful VR initiative must be cost-effective (Yildirim et al., 2020). Approaches such as using low-cost VR viewers, such as Google Cardboard-like devices with smartphones, or setting up shared VR labs in schools have been piloted to keep costs down (Cook et al., 2019). This approach could be informative in African contexts in which budgets are tight. India has also experimented with cloud-based content delivery, allowing schools to download a library of VR field trips once devices are in place (Vemuri et al., 2024). A key takeaway for Sub-Saharan Africa is that collaborative partnerships and open educational content can support the sustainability of virtual field trip programs. For example, African schools might partner with universities or local content creators to obtain locally relevant VR content, such as how Indian schools access content from domestic startups and government sources (Ahmed, 2017).

Teachers observe increased student attention and comprehension, particularly in abstract subjects, and students are highly engaged during virtual field trips (Cheng, 2021). By documenting such impacts, proponents in India have persuaded administrators to invest in virtual reality (VR) kits (Das, 2021). In the SSA context, presenting evidence, as seen in the cases of Zimbabwe and Kenya, can similarly build support among policymakers to fund and expand virtual field trip programs (Simmons et al., 2021). Virtual field trips represent a promising intersection between education, technology, and sustainability (EDEH,2024). In sub-Saharan Africa, they are opening doors for students to experience places and issues beyond their immediate surroundings without incurring the environmental and financial costs of travel (Buyego et al., 2022). India's early ventures in VR education underscore the importance of careful integration, teacher training, and cost management (Roy, 2024). India's low-cost technology and curriculum alignment strategy can serve as a model for SSA countries, as they develop these programs (Vishwanath, 2017). Virtual field trips cannot fully replace in-person experiences; however, they can enhance their experience. They are powerful tools for ensuring equitable access to experiential learning in an environmentally conscious manner (Holuša et al., 2023). African countries can enhance this instrument for the greatest possible educational and environmental impacts by taking references from India (Silaji & Masudi, 2024).

E-Waste Recycling in Education

The proliferation of technology in education, from computers and tablets to projectors and laboratory equipment, has drawn attention to the issue of electronic waste (e-waste) within the education sector (Haleem et al., 2022). The term "e-waste" refers to discarded electrical or electronic equipment, which often contains hazardous substances (such as lead, mercury, and cadmium) that, if improperly handled, can pose a risk to human health and the environment (Sunder, 2021). Using new gadgets and digital materials is simply one aspect of utilizing green technology in the classroom; another aspect is ethically managing the technology's life cycle ethically (Zhang,2023). This involves educating students about the environmental impact of technology, encouraging recycling habits, and promoting safe disposal of e-waste. Many sub-Saharan African countries face growing e-waste challenges owing to the increasing use of second-hand electronic devices for the dissemination of Information and Communication Technology (ICT), which are generally imported from the Western world (Maphosa, 2020). At the same time, the formal recycling infrastructure is limited. Integrating e-waste awareness and recycling programs into educational settings serves a dual purpose: it enables schools to handle obsolete equipment in a sustainable manner (Nyeko, 2022). At the same time, it utilizes the process as a learning opportunity for students with environmental citizenship (Kavil, 2025).

E-Waste Challenges and Education in Sub-Saharan Africa

The e-waste problem in sub-Saharan Africa has been documented as a serious environmental threat (Maphosa, 2020). Millions of tons of e-waste are generated annually in the region, primarily from imported second-hand electronics and a growing domestic consumer base (Lin et al., 2015). However, only a small fraction of this waste was correctly recycled. For instance, Kenya produces an estimated 51,000 metric tons of e-waste annually, of which only approximately 1% is recycled (Neyole et al., 2024) . The rest often end up in landfills or informal dumpsites, leading to soil and water contamination (Mutui,2020). Recognizing this, educators and policymakers in Africa are increasingly turning to the education system as a leverage point for change, both by building green skills for jobs in recycling and by instilling responsible habits early on (Obani,2025).

Several Kenyan Vocational Education and Training (VET) institutions have developed the country's first curriculum for e-waste management technicians, supported by an EU-funded consortium (Eicker, 2017). The curriculum encompasses practical skills for dismantling electronics, recovering valuable materials, and safely handling hazardous components, all of which aim to create a new cadre of professionals who can enhance recycling rates (Lenz, 2019). This addresses an environmental need by reducing the amount of e-waste that goes unrecycled in Kenya and providing employment opportunities in the green sector (Grandhi et al., 2024).

Beyond formal curricula, many SSA countries incorporate e-waste topics into school environment clubs and public awareness campaigns (Etim, 2024). For example, South Africa's recycling authorities partnered with the media to reach students. Some African schools have also launched e-waste collection drives and competitions as practical engagements (ACET, 2025). For instance, schools in Nigeria and Ghana have been reported to partner with NGOs to serve as community drop-off points for old phones and computers, which are then sent to authorized recyclers (Buertey,2018). These drives educate students by involving them directly; they learn how recycling works and why it is necessary, sometimes even visiting recycling facilities as a modern "field trip" imbibe the habit of recycling among students (Türkmen, 2023). Youth involvement has a ripple effect: students often become ambassadors of e-waste awareness in their households, encouraging their parents and neighbors to dispose of electronics safely (Ahmed, 2017). Such grassroots educational efforts are crucial in SSA, as formal e-waste management systems are still in their infancy in many countries (Maphosa, 2020).

E-Waste Education and Management in India: Lessons for SSA

India's trajectory in e-waste management offers valuable lessons for Sub-Saharan Africa as both regions are developing and experiencing a surge in electronic waste (Deshwal, 2025). By volume, India ranks among the world's top manufacturers of e-waste, producing over 2.6 million tonnes annually as of the late 2010s (Chalana et al., 2023). To address this, the Indian government introduced strict regulations, specifically e-waste (management) rules, first notified in 2011 and updated in 2016, which mandates that producers take responsibility for recycling (Extended Producer Responsibility) (Thukral & Singh, 2023). E-waste can only be processed by authorized facilities. While enforcement is ongoing, there is also parallel recognition that public awareness and education are crucial to managing e-waste sustainably in the long run (Deshwal, 2025). In the education sector, India has adopted a multi-faceted approach. Policy integration is one aspect: Environmental education is part of the national curriculum, and the newest National Education Policy (NEP, 2020) explicitly calls for comprehensive environmental education, including waste management, at all levels (Ramesh, 2022). This means that topics such as e-waste find their way into textbooks and classroom discussions in science and social studies (Ahmed, 2017). Furthermore, most Indian states have established eco-clubs in schools as part of their government's environmental programs. These Eco-Clubs, often run by the Ministry of Environment in schools as extracurricular groups, engage students in activities such as recycling paper, managing school gardens, and collecting e-waste (Roberts, 2009). The partnership between the Bajaj Foundation and UNICEF's YuWaah initiative in 2023–24 exemplifies a focused campaign, as they launched an e-waste awareness and reduction campaign, building on the school eco-clubs (India CSR, 2025). The campaign aimed to institutionalize e-waste education, rather than making it a one-time event, by integrating it into existing school clubs and aligning it with the focus of NEP 2020 (Joseph et al., 2025).

School-level e-waste programs backed by businesses and local governments are another strategy in India (Gupta et al., 2014). For example, electronics companies and NGOs have run programs in which schools serve as collection points for community e-waste (Turaga et al., 2019). For instance, Panasonic India partnered with 200 schools to install e-waste bins and conduct periodic collections complemented by student workshops on recycling (Kaur Harleen, 2019). One particularly innovative model of linking education with e-waste management in India comes from non-profit Camara Education, which operates in multiple countries, including African nations (Ganguly, 2016). In India and Africa, Camara's model aims to refurbish computers used for educational purposes and then safely recycle them at the end of their lives (Sánchez-Carracedo & López, 2021). Extension of the life of electronics via reuse in schools and creation of a "closed loop" where those devices are collected and disposed safely (Ylä-Mella et al., 2022).C amara and its partners followed certified processes (ISO 14001 standards) to ensure that zero e-waste is sent to landfills, demonstrating that even within an educational project, proper e-waste handling can be integrated (Fernandes et al., 2021). SSA educational systems can adopt similar models. For instance, large companies or charities that provide refurbished computers to schools should also help establish e-waste take-back schemes (Lawless, 2008). India's push for corporate social responsibility has led some firms to sponsor education-linked recycling efforts, a strategy that can also be encouraged in Africa (Kaur Harleen, 2019) .

From India's experience, integrating e-waste topics into youth engagement and skill-building initiatives is crucial for SSA. India now sees university programs and technical institutes offering e-waste management and recycling technology courses, thereby professionalizing the field (Yadav, 2025). SSA could similarly incorporate e-waste management into technical education, much like Kenya's VET curriculum (Zickafoose et al., 2024). Another lesson is that awareness campaigns can leverage popular culture. India has employed various methods ranging from school contests to social media challenges to encourage students to think about e-waste (Heinrich et al., 2025). African countries, as exemplified by the Cartoon Network, are already harnessing the media; continuing to do so with culturally relevant messaging can amplify their reach (Hamelin & Halawa, 2024).

Addressing e-waste through education requires policies, curricula, and community initiatives to work in tandem (Lenz, 2019). Schools in sub-Saharan Africa are beginning to play a role in e-waste solutions, and training technicians to educate children on safe disposal are all tools used by educators to make it a habit (Moyo et al., 2023). India's journey, which includes formal rules and active school programs, underscores that sustainable impacts come from consistency and scale: making e-waste education an ongoing part of school life and linking it to actual actions, such as recycling drives and other initiatives has actually paid off (Deshwal, 2025). By learning from India's policies and school-based interventions, SSA countries can accelerate their adoption of best practices, ensuring that, as they embrace more technology in classrooms, they also cultivate a culture of environmental responsibility to manage the byproducts of that technology (Zickafoose et al., 2024).

Digital Textbooks and Sustainable Learning

An important aspect of utilizing green technology in education is the shift from traditional printed textbooks to digital textbooks, also known as e-textbooks (Haleem et al., 2022). Digital textbooks are electronic copies of course materials that can be accessed by computers, tablets, and e-readers (Kamis et al., 2019). This change can significantly reduce the amount of paper used and the carbon footprint resulting from the production and distribution of physical books, which has consequences for sustainability (Chowdhury, 2012). However, success in digital textbook adoption depends on infrastructure (electricity, devices, and internet connectivity) and stakeholder acceptance (teachers' and students' willingness to use e-resources) (Altawalbeh et al., 2023). Students often appreciate the convenience of e-textbooks, while teachers emphasize the need for training and proper implementation strategies (Lin et al., 2015) . In exploring digital textbooks in SSA, we consider how countries implement e-textbook initiatives and what lessons can be drawn from India's extensive experience in this domain.

Digital Textbook Initiatives in Sub-Saharan Africa

Several countries in Sub-Saharan Africa have begun introducing digital textbooks in schools and higher education, aiming to improve access and modernize pedagogy (Chimbunde & Jakachira, 2024). In Nigeria, the state of Osun's famed "Opon Imo" project (2013) provided tablet computers pre-loaded with textbooks and interactive content to all public senior secondary students (Sanusi et al., 2017). These tablets contained interactive digital versions of all core textbooks, tutorial videos, and practice quizzes, enabling a self-paced learning experience without internet connectivity (Ifeduba & Ohikhena, 2020). An evaluation of Opon Imo found a generally positive reception: most students found the tablet easy to use. They felt that it supported their learning effectively regardless of whether they were from urban or rural schools (Adeniyi, 2019) . Even students in remote areas, many of whom had limited prior exposure to computers, reported that they could operate the device "with ease," likely reflecting the growing familiarity with mobile phones in African communities, which facilitated technology adoption (Tijani, 2016). Students valued benefits such as having all materials in one lightweight device, eliminating the need for heavy backpacks or missing books, and appreciated features such as quizzes for self-assessment (Pambudi, 2024). South Africa is also at the forefront of e-textbook trials. In the mid-2010s, some South African private and public schools replaced print books with tablets (Nel, 2014). Students see clear advantages, such as lighter school bags, because all notes and books are in one place, and no "forgotten textbook" excuses (Mello & Matthee, 2019) . Teachers in that study emphasized the need for adequate infrastructure (reliable power, Wi-Fi) and that their teaching strategies had to evolve, shifting from a teacher-led approach to more facilitated learning with digital content (Schlebusch, 2024)

Many students felt at ease reading digitally and appreciated the multimedia elements and searchability of e-textbooks (Pambudi,2024). This counters the common assumption that learners in developing regions

universally favor printed material; instead, it suggests that with increasing digital literacy, students readily embrace e-textbooks when the platform is convenient, and the content is accessible (Millar, 2015).
Kenya Education Cloud, an online platform developed by the Kenya Institute of Curriculum Development, now offers e-textbooks and interactive content for various subjects (Kiyuka et al., 2024). While the early phases faced implementation issues, including device procurement and teacher preparedness, the programme established a foundation for e-textbook use (Johnson, 2016). Countries like Rwanda and Uganda have collaborated with organizations such as World reader, which supplies e-readers with hundreds of local and international e-books, to introduce digital reading in schools and libraries (Mugamba, 2025). These initiatives often highlight the inclusive potential of digital textbooks, for example, by making content available in multiple languages or creating accessible digital textbooks for learners with disabilities (Pambudi, 2024). In partnership with UNICEF, Kenya piloted accessible e-textbooks that follow Universal Design for Learning principles to better serve visually or hearing-impaired students (UNICEF, 2022).
The project reports and literature highlight the difficulties in SSA's transition to digital textbooks. Significant infrastructure constraints include erratic Internet and electrical availability, which can interfere with frequent device use were reported (Achieng & Malatji, 2022). To overcome this issue, many projects have turned to offline solutions such as solar charging stations and pre-loaded materials. Teacher training and attitudes are other key factors; some teachers initially resist e-textbooks, feeling that they are not adequately consulted or trained (Canals, 2018). Affordability and device maintenance are sustainability concerns; if a tablet breaks and cannot be quickly repaired, students simultaneously lose access to dozens of textbooks simultaneously (Botelho, 2021). Therefore, while digital textbooks promise long-term cost savings (one device replacing many books and e-books is often cheaper than print), the upfront investment and maintenance ecosystem requires careful planning (Mardis, 2013). Studies suggest providing technical support and phased integration, for instance, by starting with a few subjects digitally, while others remain on paper until everyone is adjusted (Kraus et al., 2022).
Despite these hurdles, the trend in SSA is shifting toward greater use of digital learning materials, accelerated by the recent push for remote learning solutions during the COVID-19 pandemic (Babbar & Gupta, 2022). Schools now depend more than ever on digital resources because of the pandemic, which emphasizes the importance of strong e-textbook platforms. Governments are revising their regulations to cover the creation and dissemination of digital information (Ndibalema,2022).

India's Digital Textbook Experience and Its Relevance to SSA

India offers a compelling comparative perspective on digital textbooks, as it has implemented some of the world's most extensive digital curriculum programs (Saiju et al., 2025). The flagship initiative is the e-Pathshala platform was launched by the National Council of Educational Research and Training (NCERT) and Ministry of Education (Kadian, 2024). E-Pathshala is a nationwide digital library of textbooks and other educational resources, offering free access to over a thousand e-textbooks from grades 1 to 12 in multiple languages (Mulla Sadaqat, 2023). By making official textbooks available in PDF and mobile-friendly formats, India addressed the issues of textbook shortages and reached students beyond the physical distribution limits (Piramanayagam, 2020). This platform has been widely used, with millions of downloads recorded in the initial years. This became especially crucial during the COVID-19 pandemic, when distributing physical books became more challenging (Vidyasagar, 2022). The government integrated innovation into textbooks through QR codes printed in the books, referred to as "energised textbooks" (Vengatesh, 2023). Scanning these QR codes via a phone or the DIKSHA app (Digital Infrastructure for Knowledge Sharing) provides students with access to supplementary digital content aligned with the chapter, including videos, simulations, and assessments (Rajamani Ravi, 2024). With this method, students who have hard copies can easily transition to interactive information, fusing the depth of digital media with the dependability of a textbook (Rizky & Anggraini, 2023).
Several key lessons can be learned from India's experience with DT adoption of digital textbooks (Hennessy et al., 2022). First, central coordination and open licensing: NCERT books are openly licensed, allowing for free sharing of digital versions (Mulla Sadaqat, 2023). This open-access model allowed states and NGOs to redistribute content or adapt it with permission to local languages (UNICEF,2022). SSA countries might similarly consider Open Educational Resources (OER) policies to ensure that digital textbooks are freely accessible and can be localized (Moosa Sadruddin, 2022). Second, platform and device

diversity: India delivers e-textbooks via web portals, dedicated apps, and even offline via DVDs or pen drives to address the divide (Hillier, 2017).

For SSA, a combination of delivery modes (online and offline) can maximize reach; for example, distributing content on memory cards for schools with no Internet can suffice the purpose (Burns, 2023). Third, regarding teacher engagement, India undertook large-scale teacher training to use digital resources. Thousands of teachers in regions such as Goa were explicitly trained to use online textbooks and the e-Pathshala app, learning how to help students navigate e-books and download content for offline use (Nag & Majhi, 2025) . This underscores the importance of investing in human capital, which is as crucial as investing in technology (Bai, 2024). India has demonstrated how digital textbooks align with broader educational objectives (Mardis, 2013). To ensure that students in remote areas can access the same updated textbooks as those in urban areas, e-Pathshala and DIKSHA expanded, thereby improving equity and quality by 2019 (Rajamani Ravi, 2024).

By 2019, India's enrolment in higher education had risen to 26.3%, a steady increase partly attributed to improved access to learning resources and distance-learning platforms (Naik et al., 2024) . Although many factors contribute to this, digital initiatives play a supporting role in widening access (Saiju et al., 2025). In SSA, the average enrolment in higher education is only approximately 6%. Adopting digital textbooks alongside online learning can help students bridge the transition from secondary to tertiary education by enabling self-learning and exam preparation with readily available materials (Susilo & Suhardi, 2024).

Another lesson from India concerns the importance of sustainability and scale. By institutionalizing platforms such as DIKSHA (which hosts textbooks as well as curricula, teacher training content, and assessments), the Indian government created a one-stop solution that is cost-effective at scale (Bai, 2024). SSA countries could collaborate or draw inspiration from developing their centralized digital content repositories, potentially even sharing content for universal subjects (such as math and science basics), while tailoring content for local relevance. (Daramola,2022). Some African initiatives, such as the African Virtual University's OER repository and the Rwanda Education Board's e-learning platform, share this approach, but could be further expanded with additional content and users (Ruhinda, 2013).

User behavior and preference insights from India can inform SSA's efforts. Studies in India have found that while younger students sometimes prefer physical books for ease of reading, they quickly adapt to digital formats (Subaveerapandiyan, 2021). On the other hand, older students increasingly favor digital formats due to features such as search and portability (Abbas, 2023). However, issues like "technostress" or screen fatigue have been noted when digital materials are poorly designed (Novak et al., 2023). Thus, the quality of the digital interface matters, and a poorly scanned PDF is insufficient. E-textbooks should be optimized for reading on screens and allowing annotations, among others. Ensuring that the digital solution is user friendly will drive voluntary adoption (Yongli Zhou, 2010). A South African study has already indicated that students find e-texts useful and combining this with the Indian approach of enriching e-textbooks with multimedia and interactive elements could yield even more excellent educational benefits in Africa (Nel, 2014). By reducing paper usage, digital textbooks can help many SSA schools address their long-standing shortage of instructional resources, lower printing and distribution costs, and support their environmental objectives (Mardis, 2013).

Investing in infrastructure, especially electricity, possibly through solar solutions for schools and providing training, is essential to realizing these benefits (Barrett et al., 2019). India's journey demonstrates that digital textbook programs can become an integral and regular part of education when implemented on a scale with government backing (Srideviponmalar et al., 2023). By tailoring these lessons to their specific contexts, African countries are gradually building ecosystems, comprising policies, platforms, and practices, which will enable digital textbooks to flourish, thereby improving learning outcomes while advancing environmental sustainability in the long run (Haleem et al., 2022).

RESULTS AND DISCUSSION

Virtual field trips

Virtual field trips in Africa are not just high-tech gimmicks but are also integrated with learning objectives (Silaji & Masudi, 2024). Education specialists in Kenya have observed that VR boosts empathy (Mutabari, 2024). Immersing children in scenarios involving animals harmed by trash elicits emotional engagement that can lead to more profound learning (Louise Zanoni, 2018). These qualitative outcomes align with global research findings that VR can evoke the "right emotions" and foster collaborative problem-solving among students, thereby reinforcing content knowledge and skills, such as empathy and teamwork (Chopra & Kanji, 2010).

Table 1: VR Usage Insights in specified countries

Country	VR Usage Domains	Key Insights	References
Kenya	Education, Public Engagement	Growing use in schools and public education; notable initiatives include virtual research tours.	(Silaji & Masudi, 2024)
Zimbabwe	Tertiary Education	Frameworks proposed for VR integration; challenges include infrastructure and digital access.	(Nherera & Mukora, 2024)
South Africa	Education, Healthcare, E-Commerce,	Adoption in healthcare, training, and retail is emerging, with educational use also gaining traction, but barriers persist in rural areas.	(Shambare,2025; Mkwizu,2022)
India	Open Schooling, Classroom Education	Advanced integration in open schooling and classrooms serves as a model for other regions.	(Yildirim et al., 2020)

India's experience with virtual field excursions and VR education offers valuable lessons (Swargiary, 2023). One realization is the necessity for local content and teacher preparedness. Indian teachers who have used VR report that proper training and alignment with the syllabus are crucial; the virtual trip must be tied to lesson objectives, for it to be more than just entertainment (Nandi et al., 2023). To address this, some Indian ed-tech firms have created VR content aligned with the national curriculum (for instance, a virtual field trip to a biodiversity park aligns with an environmental science unit) (Heuke et al., 2024).

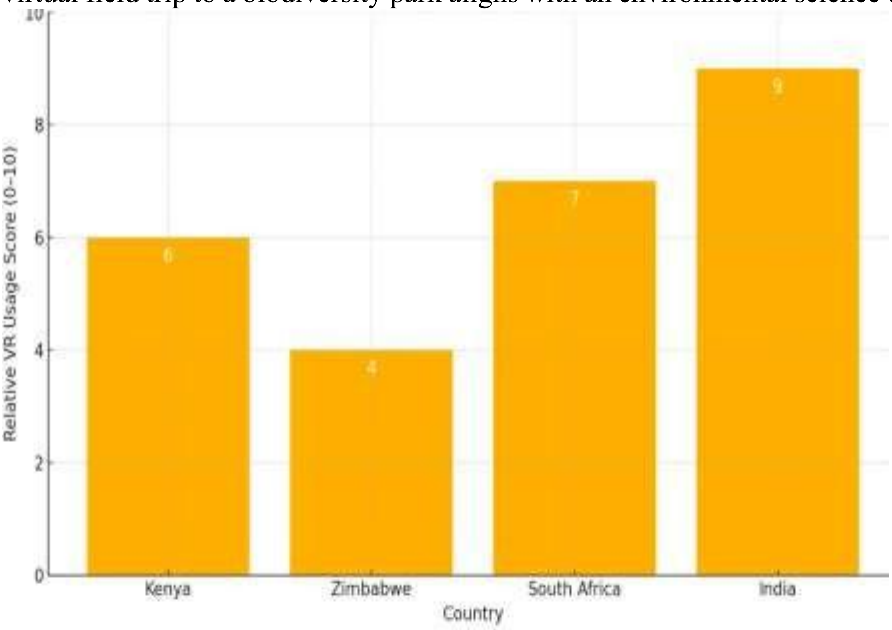

Figure 1, Comparative VR Usage in Education and Public Engagement
(Compilation based on Shambare,2025, Mutabari,2024)

South Africa and India are at the forefront of VR use, indicating a more sophisticated digital adoption. To improve VR integration in areas such as training and education, Zimbabwe needs focused assistance, but Kenya is making encouraging strides.

E-Waste Recycling in Education

Education on e-waste recycling is emerging as a critical strategy for promoting environmental sustainability and technological literacy in developing and transitional economies. To promote safe electronic disposal, educational institutions in India have begun integrating e-waste awareness and recycling initiatives into their curricula at both school and university levels. This is achieved by utilizing the nation's organized recycling system (Ghulam, 2023). Similarly, South Africa engages higher education institutions in e-waste collection and digital sustainability education; however, formal recycling participation remains under 12%, constrained by limited integration with national policies (Moyo et al., 2023)

Table 2: E-Waste Generation Statistics

Country	**Total E-Waste Generated**	**Key Challenges**	**Reference**
India	1.751 million metric tonnes (2023–24)	Rapid growth in electronic consumption, dominance of the informal recycling sector	(Deshwal, 2025)
Nigeria	500,000 metric tonnes (2022)	High volume of imports, lack of formal recycling infrastructure	(Traverso et al., 2024)
South Africa	360,000 metric tonnes (2023)	Low formal recycling rates, significant informal sector involvement	(Moyo et al., 2023)
Kenya	51,000 metric tonnes (2024)	Limited formal recycling facilities, growing e-waste from small electronics	(Neyole et al., 2024)

Kenya and Nigeria face infrastructural and policy gaps, where informal e-waste management prevails, and educational interventions are often pilot-based and frequently supported by NGOs or international collaborations (Traverso et al., 2024). In this context, promoting e-waste literacy through curriculum reforms and campus recycling initiatives could empower youth as environmental stewards and catalyze the growth of formal recycling channels. The results of Bhutta et al. (2011), who emphasize that integrating e-waste education into school systems promotes behavioral change and facilitates the establishment of long-term waste management infrastructure, are consistent with this.

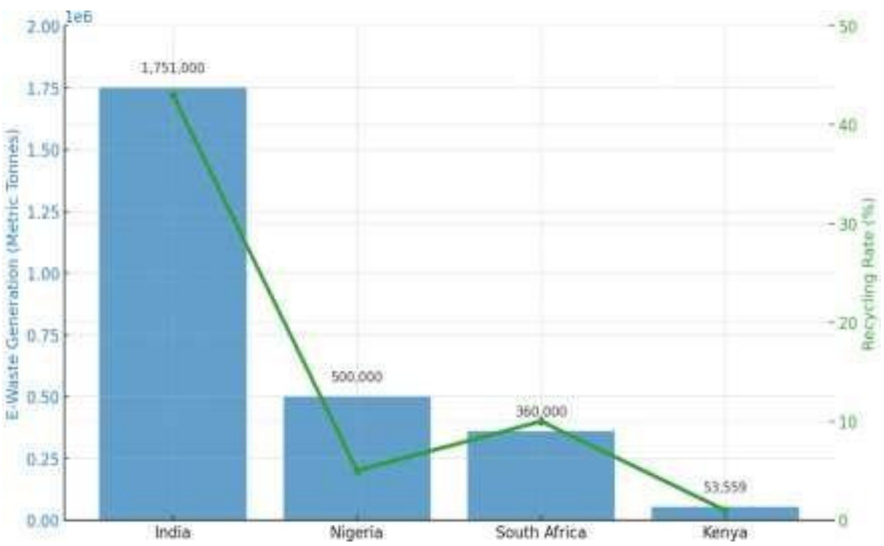

Figure 2, E-Waste Generation and Recycling Rates (India, Nigeria, South Africa, Kenya) (Compilation based on Deshwal, 2025; Traverso et al., 2024; Moyo et al., 2023; Neyole et al., 2024)

India leads in both e-waste generation and recycling efficiency, while Nigeria and Kenya lag in terms of formal recycling facilities. South Africa performed an average on both fronts. The data highlight the need for improved e-waste recycling systems, especially in African countries, where informal disposal poses significant environmental and health risks.

Digital Textbooks and Sustainable Learning

Digital content offers the opportunity to widely distribute current learning resources at a lower long-term cost in areas with chronic textbook shortages or high textbook costs (Lee et al., 2020). However, many students feel at ease reading digitally and appreciate the multimedia elements and searchability of e-textbooks (Pambudi,2024). This counters the common assumption that learners in developing regions universally favor printed material; instead, it suggests that with increasing digital literacy, students readily embrace e-textbooks when the platform is convenient, and the content is accessible (Millar, 2015).

Other SSA countries have pursued digital textbook initiatives, often in conjunction with broader ICT-in-education programs (Agyei, 2021). Kenya, for instance, introduced the "Digital Literacy Programme" (Digi School) in 2016, providing tablets to primary school pupils loaded with digital content to support a new competency-based curriculum (Werimo & Muthee, 2022).

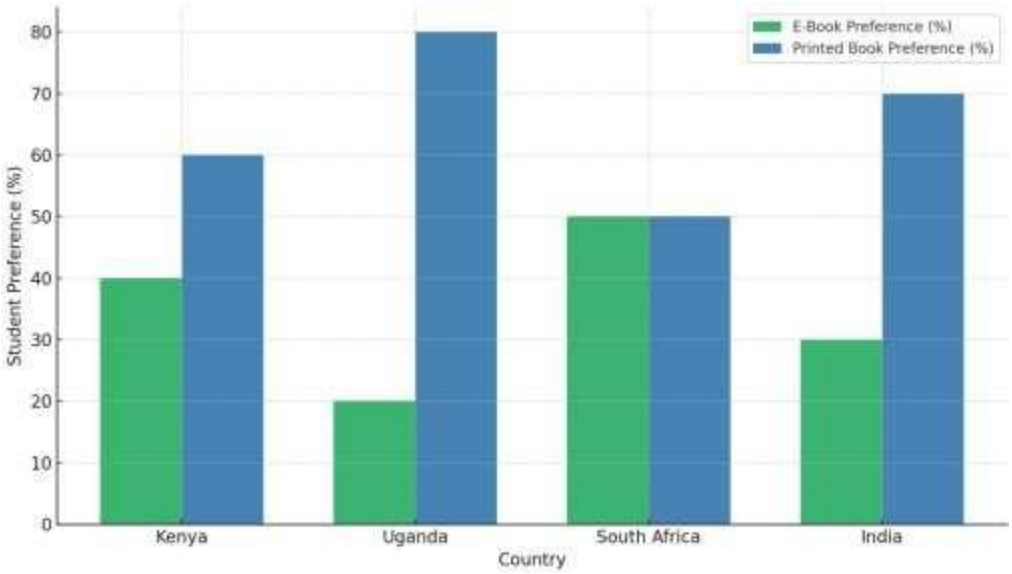

Figure 3 Student Preference for E-Books versus Printed Books.
(Compilation based on Subaveerapandiyan,2021, Millar, 2015 Nel, 2014)

While Students in Kenya prefer printed materials, South Africa appears to be evolving into a digitally adapted school environment, accepting both e-books and printed books equally. Printed books continue to be popular worldwide, particularly in Uganda and India. South Africa stands out for its equal preference, which could indicate an improved digital integration in education.

CONCLUSIONS

A vital opportunity exists in Sub-Saharan Africa (SSA) to align pedagogical innovation with environmental sustainability by integrating green technology into education. According to the review, adopting digital textbooks, e-waste recycling programs, and virtual field trips (VFTs) are viable strategies that can improve learning outcomes while reducing ecological footprint.

Virtual field trips have shown promise in democratizing experiential learning. Empirical studies from Kenya and Zimbabwe have demonstrated their effectiveness in increasing environmental knowledge and engagement. Simultaneously, India's experience demonstrates the scalability of implementation through low-cost VR solutions and curriculum alignment.

In South Africa and Kenya, e-waste recycling in educational institutions has shown great promise primarily through youth engagement and vocational training. Nonetheless, recycling rates in SSA remain extremely low. India's structured e-waste management policies and educational campaigns offer a replicable model, mainly through formalized training programs, school-based collection initiatives, and partnerships with private sector actors.

Students in SSA and India are increasingly preferring digital textbooks because of their portability, cost-effectiveness, and ease of access. India's centralized platforms, such as e-Pathshala and DIKSHA, exemplify how policy-backed digital content distribution can bridge educational gaps and reduce dependence on paper-based materials. SSA countries can harness similar strategies to modernize learning materials while promoting sustainable resource use.

Recommendations

Based on the comparative analysis, the following recommendations are proposed for policymakers, education planners, and development partners in sub-Saharan Africa: National educational policies should explicitly integrate green technology goals, including guidelines for adopting VFTs, e-waste management, and the use of digital learning materials.

Ministries of education should work with environmental agencies to embed sustainability objectives into educational frameworks and infrastructure planning. Governments and partners should prioritize investments in electricity (especially solar power), internet connectivity, and affordable digital devices for schools, particularly in rural areas.

Digital textbook platforms should support offline access and include localized curriculum-aligned content. Continuous professional development is essential to equip educators with the skills to effectively implement green technologies. Training should include practical modules on using VFTs, integrating digital textbooks into lesson planning, and managing classroom e-waste.

India's Extended Producer Responsibility (EPR) model was adopted to create national frameworks that include school-based e-waste collection and recycling programs. E-waste management should be introduced into technical and vocational education to build a workforce for the growing green sector.

Encourage partnerships between governments, e-tech firms, and civil society to design, fund, and implement green education initiatives. Innovation hubs and start-up incubators should support local solutions, such as low-cost virtual reality (VR) and refurbished tablets, tailored to the African context.

Formalize South-South collaboration platforms where African and Indian policymakers and practitioners can share best practices, resources, and co-develop solutions. Pilot joint initiatives include the development of VR content, teacher exchange programs, and co-authored digital textbook repositories.

Conflict of Interest declaration:

The authors declare that they have no affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

Ethical Compliance:

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