



Artificial intelligence and sustainable development in Africa: A comprehensive review

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ARTICLE INFO

Keywords:

AI
Africa
Deep learning
Machine learning
Sustainable development
SDG

ABSTRACT

Artificial Intelligence (AI) techniques are transforming various sectors and hold significant potential to advance sustainable development in Africa. However, their effective integration is constrained by region-specific challenges, limiting widespread deployment. This study reviews the current state of sustainable development in Africa, highlighting the role AI can play in driving progress across key sectors, including healthcare, agriculture, education, environmental protection, and infrastructure. The paper outlines the challenges hindering AI adoption and presents strategic approaches to address these obstacles, specifically targeting Africa's socio-economic and environmental needs. In addition, the study proposes a comprehensive framework for integrating AI into Africa's sustainable development efforts, offering tailored AI-driven strategies that align with the continent's unique context. This framework provides a valuable resource for AI researchers, policymakers, and practitioners working towards sustainable development in Africa.

1. Introduction

Artificial intelligence (AI) has progressively transformed from a niche technological innovation to a powerful tool capable of solving complex and multidimensional problems across various sectors (Bibri, Krogstie, Kaboli, & Alahi, 2024; Mienye & Jere, 2024a; Neethirajan, 2024). Its applications in sustainable development are promising, offering state-of-the-art changes in areas crucial for economic growth, social equity, and environmental sustainability (Singh, Kanaujia, Singh, & Vinuesa, 2024; Triguero, Molina, Poyatos, Del Ser, & Herrera, 2024). In recent years, there has been a growing interest in harnessing the capabilities of AI to address pressing challenges in Africa, a continent that is often disproportionately affected by issues such as poverty, climate change, and lack of access to basic services (Azzarri & Signorelli, 2020; Priscilla & Camargo, 2020; Rutenberg, Gwagwa, & Omino, 2021).

Meanwhile, AI can be characterized as the branch of computer science that focuses on the creation of intelligent agents, which are systems that perceive their environment and take actions that maximize their chances of successfully achieving their goals (Tiwari, 2024). This involves the simulation of cognitive processes that are associated with human intelligence, such as learning, reasoning, problem-solving, perception, and language understanding (Harika, Baleeshwar, Navya, & Shanmugasundaram, 2022). Specifically, AI systems use algorithms and dynamic modeling to process data, make decisions, and learn from

outcomes, often surpassing the speed and accuracy of human capabilities in various tasks (Mienye & Jere, 2024c). Specific applications of AI include natural language processing (NLP), speech recognition, and image recognition (Hirschberg & Manning, 2015; Lu, Zheng, Carneiro, & Yang, 2017; Tetard, Carlsson, Meunier, & Danelian, 2023). Sustainable development, on the other hand, refers to the organizing principle for meeting human development goals while simultaneously sustaining the ability of natural systems to provide the natural resources and ecosystem services upon which the economy and society depend (Liu et al., 2018; Mensah, 2019).

While AI holds immense potential to accelerate sustainable development in Africa, its application faces several challenges that are not adequately addressed in current research. In Africa, where the challenges are as diverse as they are significant, AI offers a promising tool to accelerate progress towards the sustainable development goals (SDGs) established by the United Nations in 2015 (Palomares et al., 2021). These goals aim to address global challenges such as poverty, inequality, climate change, environmental degradation, peace, and justice (Bickley, Macintyre, & Torgler, 2024). For example, AI-powered applications in agriculture can predict weather patterns and optimize planting cycles, thus boosting crop yields and resilience to climate variability (Javaid, Haleem, Khan, & Suman, 2023; Shaikh, Rasool, & Lone, 2022). In healthcare, AI models are being developed to diagnose diseases from medical images, significantly improving the

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reach and quality of medical services in underserved regions (Bohr & Memarzadeh, 2020; Schwalbe & Wahl, 2020).

Despite the promise, there remains a critical gap in current literature concerning AI's role in addressing the unique socio-economic and environmental challenges faced by Africa. Most existing studies generalize the findings from other regions, often overlooking Africa's distinct contexts. This paper aims to bridge this gap by exploring the intersection of AI with sustainable development in Africa, identifying both the opportunities and challenges presented by this collaboration. The specific goals and contribution of this study include:

- Examine current AI implementations across various sectors globally and analyze their impact on sustainable development, while highlighting their adaptability and relevance in the African context.
- Discuss the specific challenges and opportunities presented by AI in Africa, providing insights into contextual adaptation and strategic alignment with SDGs.
- Propose strategic frameworks to effectively leverage AI technologies for sustainable development tailored to meet Africa's unique needs.

The rest of the paper is structured as follows: Section 2 presents a review of related works, and Section 3 discusses the research methodology. Section 4 presents an overview of AI and sustainable development within the context of Africa. Section 5 discusses how AI can drive sustainable development in Africa, especially in key sectors such as healthcare, agriculture, education, and the environment. Section 6 presents challenges and strategies for optimizing AI for sustainable development in Africa. Section 7 proposes a framework for AI integration in Africa's sustainable development. Section 8 discusses future research directions, while Section 9 concludes the study.

2. Related works

The integration of AI in sustainable development has been the subject of extensive research globally, though the focus on Africa is comparatively recent. Several works have highlighted the potential of AI in promoting sustainable development goals worldwide. For instance, Vinuesa et al. (2020) provided a systematic review of how AI impacts all seventeen SDGs, noting that while AI has the potential to enable achievements across all goals, it also poses risks that could hinder progress if not managed carefully. Similarly, Rolnick et al. (2022) discussed how machine learning (ML) could address key challenges in climate prediction, agriculture, and energy consumption, which are essential for environmental sustainability.

Focusing on Africa, studies such as Smith (2018) have examined how AI technologies like ML and data analytics are being deployed in agricultural sectors to predict crop yields and optimize resource use, which is critical for ensuring food security in sub-Saharan Africa. Another significant contribution by Alshamrani (2022) looked at AI in the healthcare sector, specifically how AI-powered diagnostic tools are transforming disease identification and patient management in remote areas.

The literature also extensively covers the challenges and ethical implications of deploying AI. Sallstrom, Morris, and Mehta (2019) discussed the infrastructural and ethical barriers to the implementation of AI in African healthcare systems, particularly issues surrounding data privacy and the lack of tailored AI solutions for local contexts. Additionally, the work by Kolade and Owoseni (2022) focuses on the social implications of AI, including job displacement and the risk of exacerbating existing inequalities.

Furthermore, recent studies emphasize the need for robust governance structures to manage AI deployment. For example, Ayana et al. (2024) evaluated the effectiveness of current AI policies in several African countries, identifying gaps in data governance, which could

hinder equitable access to AI technologies. They argue for more comprehensive regulations to safeguard against biases and ensure ethical AI usage across different sectors. Similarly, Mir, Kar, and Gupta (2022) highlighted the importance of AI literacy among policymakers and stakeholders to better understand the socio-economic impacts of AI, especially in areas with limited digital infrastructure. These insights underline the critical need for AI policy reform and capacity building to maximize AI's impact on sustainable development.

Significant contributions have also been made by scholars such as Okolo, Aruleba, and Obaido (2023), which analyzed the existing AI policies in Nigeria, South Africa, and Kenya. Their research suggests that while these countries are making strides in creating conducive environments for AI innovations, gaps in regulation and alignment with global standards remain a concern. Meanwhile, Brini (2021) highlighted that a more integrated approach that combines AI with renewable energy technologies is necessary to tackle climate change in Africa. This work suggests that interdisciplinary research combining ICT, environmental science, and policy studies will be crucial in realizing the full potential of AI in sustainable development.

Recent studies continue to examine the expanding role of AI in driving sustainable development within specific African contexts. For instance, Domingo, Mbatha, Gumbo, and Mphambukeli (2024), in their study, explored the integration of AI in urban planning and public transportation systems in Johannesburg, South Africa. They demonstrate how AI-enabled traffic management systems can reduce congestion and pollution, thereby enhancing urban livability and sustainability. This research is crucial as it shows practical applications of AI in improving everyday life while also addressing environmental SDGs. Additionally, the work by Olatunde, Adelani, and Sikhakhane (2024) investigated the application of AI in water resource management in Africa and the United States. Their findings illustrate how AI can optimize the distribution and usage of water resources, significantly impacting agriculture and sanitation sectors, which are critical for sustainable development. These studies emphasize the tangible benefits of AI in sector-specific challenges, highlighting its potential to transform essential services and infrastructure in Africa.

Despite these significant contributions to understanding AI's role in sustainable development, the existing literature often falls short in providing a comprehensive analysis specifically tailored to the multifaceted challenges faced by Africa. Much of the research tends to generalize findings from other global contexts without adequate consideration of Africa's unique socio-economic, cultural, and environmental landscapes. This study aims to fill this critical gap by presenting in-depth insights into how AI technologies can be adapted and strategically implemented to meet Africa's specific needs. By focusing on locally relevant AI applications and considering indigenous knowledge and practices, our research provides a new perspective that bridges the gap between global technology trends and local applicability. This approach enhances the relevance of AI solutions for African contexts and also contributes to a more equitable and inclusive global discourse on AI and sustainable development.

3. Methodology

This review paper aims to provide a comprehensive analysis of how AI can contribute to sustainable development in Africa, with a specific focus on key sectors such as healthcare, agriculture, education, environmental protection, and infrastructure. To achieve this, we adopted a structured approach to reviewing relevant literature, ensuring a broad yet focused examination of the current state of research in AI-driven sustainable development, particularly within the African context.

3.1. Literature search and selection criteria

The selection of literature for this review followed a systematic process to ensure that the most relevant, recent, and impactful works were included. The following criteria guided our literature selection:

- **Time Frame:** We focused primarily on literature published in the last decade (2013–2024), as this period represents the most significant advancements in AI technologies and their applications in sustainable development.
- **Databases Searched:** To ensure comprehensive coverage, we conducted searches in prominent academic databases, including Google Scholar, IEEE Xplore, Scopus, and Web of Science. These databases were selected due to their extensive indexing of AI and sustainable development literature across multiple disciplines.
- **Keywords:** The search strategy involved using a combination of key terms such as “artificial intelligence”, “sustainable development”, “AI in healthcare”, “AI in agriculture”, “AI in Africa”, and “AI challenges in developing countries”. This ensured the inclusion of a wide range of studies relevant to both AI and the specific sectors under review.
- **Inclusion and Exclusion Criteria:** We prioritized peer-reviewed journal articles, conference proceedings, and high-impact white papers. Studies were excluded if they focused solely on technical advancements in AI without any relation to sustainable development or if they did not include a focus on Africa or developing regions.

3.2. Review process and analysis

Once the relevant literature was identified, we employed a two-step review process:

1. **Initial Screening:** Each article was reviewed for relevance based on title, abstract, and keywords. Studies that met the inclusion criteria were selected for further analysis.
2. **In-Depth Review and Thematic Categorization:** The full texts of the selected papers were then reviewed in detail. Articles were categorized into thematic areas, focusing on their contribution to AI applications in sectors such as healthcare, agriculture, education, environmental protection, and infrastructure. Additionally, we paid attention to papers that highlighted the challenges, risks, and opportunities associated with AI adoption in Africa, providing insights into the specific socio-economic and environmental contexts of the continent.

3.3. Contribution to the literature

This review adds value by synthesizing the current body of knowledge on AI applications in sustainable development with a specific focus on Africa, a region that is often underrepresented in global AI research. Unlike previous reviews that may generalize findings from other regions, this paper addresses the unique socio-economic, environmental, and infrastructural challenges faced by African nations. Additionally, by proposing a structured framework for the application of AI technologies in key sectors, this review not only fills a gap in the literature but also provides actionable insights for policymakers, researchers, and practitioners seeking to implement AI solutions tailored to Africa's needs.

4. Background

4.1. Artificial intelligence

AI is an umbrella term that refers to a suite of technologies and methodologies aimed at endowing machines with the capability to perceive, comprehend, act, and learn, mirroring certain aspects of

human intelligence (Fogel, 2022). The field is interdisciplinary, drawing from computer science, psychology, mathematics, linguistics, and more, encompassing a diverse set of algorithms and techniques such as machine learning, deep learning, neural networks, natural language processing, and robotics. Meanwhile, machine learning is a branch of AI that involves training algorithms to make decisions or predictions based on data. This discipline enables computers to learn from and adapt to new data without being explicitly programmed for every task (Baştanlar & Özuysal, 2014). On the other hand, Deep learning (DL), a subset of ML, extends these capabilities by employing complex neural networks with many layers, or “deep” architectures, that automatically discover relevant features and patterns in the data (Mienye, Kenneth Ainah, Emmanuel, & Esenogho, 2021). Deep learning techniques are particularly powerful in handling large-scale and high-dimensional data, as seen in applications ranging from autonomous vehicles to real-time speech recognition systems. These methods have improved the accuracy and efficiency of various machine learning tasks, often performing at or above human-level capabilities in specific domains. Fig. 1 shows the distinction between AI, ML, and DL and clearly indicates different areas where these techniques are being applied to achieve SDGs.

At its core, AI strives to create systems that can function autonomously to some degree, whether it be in performing complex calculations, recognizing patterns in data, or interacting with users in a way that feels natural (Górriz et al., 2020; Sarker, 2022). The potential of AI extends across various sectors, enabling advances in healthcare through predictive diagnostics, in finance through automated trading systems, in the automotive industry through self-driving cars, and in everyday life through personal assistants. The evolution of AI is marked by milestones in computational power and data availability, propelling it from a theoretical pursuit to a practical tool driving innovation (Andreu-Perez, Deligianni, Ravi, & Yang, 2018). In Africa, AI presents a significant opportunity to leapfrog development stages, offering solutions tailored to the continent's unique challenges and harnessing its burgeoning youth demographic and entrepreneurial spirit.

The current state of AI in Africa varies widely across the continent. While some countries are emerging as leaders in AI research and development, overall, the continent faces challenges related to infrastructure, connectivity, and data accessibility. However, there are promising signs of growth, with an increase in AI-focused startups, tech hubs, and research initiatives. African governments and policymakers are beginning to recognize the importance of AI, as evidenced by the adoption of national strategies and policies aimed at promoting AI development and integration (Ade-Ibijola & Okonkwo, 2023). Moreover, partnerships between African universities, international institutions, and private sectors are fostering an environment conducive to AI innovation and education, indicating a positive trajectory for AI's role in sustainable development across Africa.

4.2. Sustainable development

Sustainable development has increasingly been at the forefront of international policy discussions, emphasizing a holistic approach to growth that ensures environmental stewardship, social inclusion, and economic development. The concept has evolved from the seminal Brundtland Commission's report in 1987 (Burton, 1987), which first coined the term to mean “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”. This notion combines the dual imperatives of meeting human needs — ensuring health, education, and justice — and extending social welfare while simultaneously protecting and managing the earth's life support systems. In 2015, this vision was further crystallized with the adoption of the Sustainable Development Goals (SDGs) by all United Nations Member States (Organization, 2015). These 17 SDGs (summarized in Table 1) form a global blueprint aimed at achieving a better and more sustainable future for all. They cover a broad spectrum

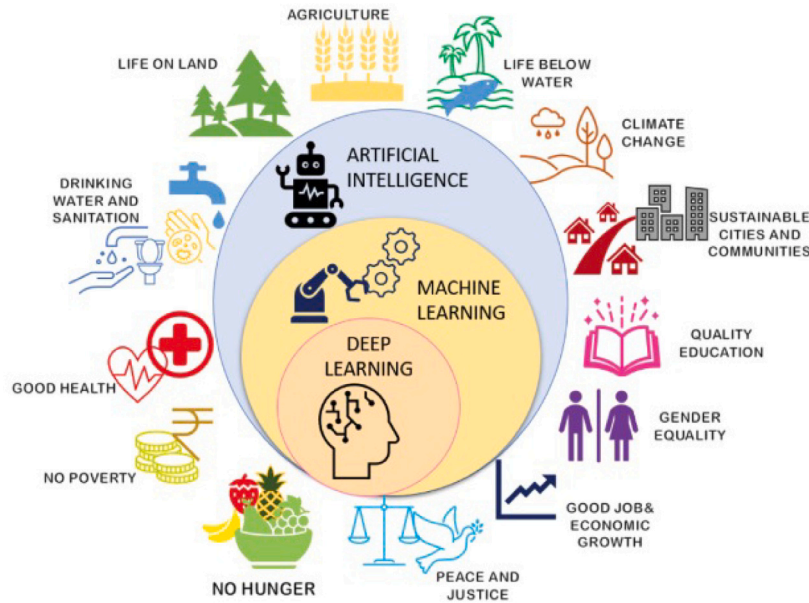


Fig. 1. AI and its subsets driving SDG (Al-Baity, 2023).

Table 1

Sustainable development goals.

Goal	Description
Goal 1	No Poverty
Goal 2	Zero Hunger
Goal 3	Good Health and Well-being
Goal 4	Quality Education
Goal 5	Gender Equality
Goal 6	Clean Water and Sanitation
Goal 7	Affordable and Clean Energy
Goal 8	Decent Work and Economic Growth
Goal 9	Industry, Innovation, and Infrastructure
Goal 10	Reduced Inequality
Goal 11	Sustainable Cities and Communities
Goal 12	Responsible Consumption and Production
Goal 13	Climate Action
Goal 14	Life Below Water
Goal 15	Life on Land
Goal 16	Peace, Justice, and Strong Institutions
Goal 17	Partnerships for the Goals

of economic, social, and environmental objectives that range from eradicating extreme poverty and hunger to ensuring access to clean water and sustainable energy, promoting peaceful and inclusive societies, and fostering innovation (Awan, 2021).

The SDGs are designed to be integrated and indivisible, recognizing that actions in one area will invariably influence outcomes in others. For instance, improvements in education and health can enhance long-term economic stability, and advances in clean energy can contribute to environmental sustainability and economic growth. The goals also emphasize the importance of partnerships and international collaborations, acknowledging that tackling global challenges such as climate change, resource depletion, and social inequality requires coordinated efforts across borders.

Moreover, the pursuit of sustainable development necessitates international cooperation and local engagement (Moallemi et al., 2020). Strategies need to be tailored to specific regional contexts, acknowledging the diverse social, economic, and environmental conditions that exist across and within countries. In Africa, this implies developing policies that address specific local challenges such as desertification, water scarcity, and urban poverty while also harnessing unique opportunities such as the continent's vast renewable energy potential and young demographic profile. The SDGs also represent a call to action

for private sector innovation, with businesses increasingly recognized as vital partners in achieving sustainable development (Rashed & Shah, 2021). The private sector can make substantial contributions to broader development objectives by promoting responsible business practices and investing in sustainable technologies. This approach helps mitigate risks and protect ecosystems and also opens up new markets and ensures long-term economic viability.

4.2.1. Categorizing SDGs: The 5Ps and dimensions

Understanding the SDGs through different frameworks can provide valuable insights into their interconnected nature and the broad spectrum of global challenges they aim to address. This section explores two popular frameworks: the 5Ps and the dimensions of the SDGs. Each framework offers a unique perspective on how the SDGs can be categorized to highlight certain thematic and operational priorities. The 5Ps framework categorizes the SDGs into five essential themes, each representing a broad area of focus that highlights the holistic approach required to achieve sustainable development (Fallah Shayan, Mohabbati-Kalejahi, Alavi, & Zahed, 2022; Tremblay, Fortier, Boucher, Riffon, & Villeneuve, 2020). These themes are People, Planet, Prosperity, Peace, and Partnership. They are described below and summarized in Fig. 2.

1. **People:** The goal to uplift People emphasizes eradicating poverty and hunger and ensuring that all human beings can fulfill their potential in dignity and equality. SDG 1, 'No Poverty', specifically targets the elimination of poverty in all its forms everywhere, which is the most fundamental challenge to sustainable development (Leal Filho, Lovren, Will, Salvia, & Frankenberger, 2021). Addressing this goal involves providing people with access to essential resources and enhancing their quality of life through education and healthcare.
2. **Planet:** Protecting the Planet involves safeguarding our ecosystems and ensuring that natural resources are managed sustainably to support current and future generations. Goal 13, 'Climate Action', indicates the urgent need to combat climate change and its impacts. This goal is critical as climate change threatens to undermine the ability of all countries to achieve sustainable development (Jung, Lee, & Park, 2018). It involves measures to strengthen resilience, improve education on climate change mitigation, and increase the capacity for effective climate change-related planning and management.



Fig. 2. SDGs grouped into 5Ps.

3. **Prosperity:** This element is about ensuring that all individuals have the opportunity to enjoy prosperous and fulfilling lives, with economic growth occurring in ways that do not harm the environment. Goal 9, 'Industry, Innovation, and Infrastructure', highlights the critical importance of building resilient infrastructure, promoting inclusive and sustainable industrialization, and fostering innovation (Tremblay et al., 2020). The focus is on developing quality, reliable, sustainable, and resilient infrastructure, including regional and trans-border infrastructure, to support economic development and human well-being.
4. **Peace:** Peace is fundamental to sustainable development. Goal 16, 'Peace, Justice, and Strong Institutions', promotes peaceful and inclusive societies for sustainable development, provides access to justice for all, and builds effective, accountable, and inclusive institutions at all levels (Tremblay et al., 2020). It involves reducing all forms of violence and ending abuse, exploitation, trafficking, and all forms of violence against and torture of children. It is about ensuring decision-making at all levels is inclusive and representative.
5. **Partnership:** The focus on Partnership stresses the importance of revitalizing the global partnership for sustainable development. Goal 17, 'Partnerships for the Goals', aims to enhance North-South, South-South, and triangular regional and international cooperation on access to science, technology, and innovation (Sharma & Varshney, 2023). It calls for knowledge sharing on mutually agreed terms, including through improved coordination among existing mechanisms and through a global technology facilitation mechanism.

The dimensions framework categorizes the SDGs into four broad dimensions, each reflecting a distinct but interrelated sphere of sustainable development: Society, Economy, Environment, and Partnerships (Berrone et al., 2019; Van Zanten & van Tulder, 2021). By examining the SDGs through these four dimensions, summarized in Table 2, stakeholders can gain a comprehensive understanding of the multiple facets of sustainable development and how integrated, cross-sectoral actions are necessary to achieve these ambitious objectives. This approach highlights how interconnected all the goals are and the need for a unified effort to address the planet's most pressing challenges. They are described below:

Table 2
SDGs categorized by dimensions.

Dimension	Goals
Economy	Goal 7, 8, 9, and 11
Environment	Goal 6, 12, 13, 14, and 15
Partnerships	Goal 17
Society	Goal 1, 2, 3, 4, 5, 10, 11, and 16

1. **Society:** The societal dimension addresses the core aspects of human well-being and aims to ensure a balanced social development across communities. It integrates goals that promote health (Goal 3), educational opportunities (Goal 4), gender equality (Goal 5), and the reduction of inequalities (Goal 10) (Dempsey, Bramley, Power, & Brown, 2011). This dimension emphasizes the necessity of equitable social progress as the backbone of sustainable development. Initiatives under this category strive to dismantle social barriers, provide equal opportunities, and ensure that all individuals have access to basic services and rights that are essential for their well-being and dignity.
2. **Economy:** Focused on ensuring prosperity for all, the economic dimension of the SDGs emphasizes the need for robust, inclusive economic growth that does not come at the expense of environmental health or social equity. This dimension includes goals aimed at promoting sustained economic growth (Goal 8), supporting industry, innovation, and infrastructure (Goal 9), and ensuring responsible consumption and production patterns (Goal 12) (Bengtsson, Alfredsson, Cohen, Lorek, & Schroeder, 2018). By fostering an economic environment that encourages entrepreneurship, creates jobs, and promotes an equitable distribution of resources, this dimension seeks to lay the foundations for a resilient and dynamic economy.
3. **Environment:** This dimension emphasizes the critical importance of protecting and managing the Earth's natural resources to ensure a sustainable future. It encompasses goals focused on ensuring availability and sustainable management of water and sanitation for all (Goal 6), affordable and clean energy (Goal 7), and taking urgent action to combat climate change and its impacts (Goal 13) (Herrera, 2019). Additionally, it addresses the necessity to conserve and sustainably use the oceans, seas, and marine resources (Goal 14) and to protect, restore, and promote sustainable use of terrestrial ecosystems (Goal 15). Through these goals, the environmental dimension highlights the interdependence of all forms of life and the need for actions that contribute to the planet's health.
4. **Partnerships:** Acknowledging the complex and interconnected nature of global challenges, this dimension emphasizes the importance of robust international partnerships (Goal 17). These partnerships are seen as crucial for pooling resources, sharing knowledge, and fostering cooperation across borders to achieve sustainable development objectives (Oliveira-Duarte et al., 2021). This dimension encourages collaboration not only among countries but also between the public and private sectors, civil society, and other stakeholders, ensuring that sustainable development is achieved through a collective effort and shared responsibility.

4.3. Sustainable development in Africa

Sustainable development in Africa faces a unique set of challenges that are complex and multifaceted. The continent is home to some of the world's fastest-growing economies, yet it remains hindered by persistent poverty, with a significant portion of the population living below the poverty line (Bhorat, Naidoo, & Pillay, 2016). Health issues are also a major concern, as Africa bears a disproportionate burden

of global health challenges, including communicable diseases such as HIV/AIDS, tuberculosis, and malaria, alongside a rising incidence of non-communicable diseases (Niohuru, 2023). The education sector grapples with issues of accessibility and quality, with many children out of school and educational systems that often fail to provide the skills necessary for the modern job market.

Environmental sustainability is another critical area, with Africa facing the brunt of climate change impacts despite contributing the least to global emissions. Issues such as water scarcity, deforestation, and loss of biodiversity are compounded by economic activities that often prioritize short-term gains over long-term environmental health (Hernández-Delgado, 2015). Meanwhile, rapid urbanization presents both opportunities and challenges, including the need for sustainable city planning and infrastructure development. These challenges are interlinked, and addressing them requires an integrated approach that considers the social, economic, and environmental dimensions of development. Sustainable development in Africa must be inclusive, ensuring that the benefits of growth and progress are widely shared and do not come at the expense of the continent's natural resources and ecological balance.

5. Utilizing AI for sustainable development in Africa

Artificial Intelligence holds significant potential for driving sustainable development in Africa, a continent with unique challenges and burgeoning opportunities. Through the integration of AI technologies in key sectors, African nations can leverage these tools to achieve rapid and sustainable growth across various domains. This section explores how AI can be utilized to achieve sustainable development in key sectors in Africa.

5.1. AI and healthcare

In the healthcare sector, the advent of AI presents major changes with the potential to revolutionize how medical care is delivered, particularly in under-resourced areas. AI technologies offer profound advancements in medical diagnosis and patient care, notably through capabilities such as telemedicine and automated disease diagnosis (Bhaskar et al., 2020; Mienye & Jere, 2024b; Nakayama et al., 2023). AI-powered systems can analyze vast arrays of medical data — ranging from patient health records to complex diagnostic images — with unprecedented speed and accuracy (Mienye et al., 2021). This capability is immensely beneficial in regions that suffer from a shortage of medical professionals and where access to quality healthcare is often limited. For example, AI-driven diagnostic tools can be employed to enhance the detection and treatment of prevalent diseases such as tuberculosis and malaria. These tools utilize ML algorithms to identify patterns and anomalies in medical images that might be missed by the human eye (Mienye, Sun, & Wang, 2020). In malaria cases, AI applications can quickly analyze blood samples to detect parasites, and in tuberculosis patients, they can analyze chest X-rays to identify early signs of infection. AI can help to significantly enhance patient outcomes and manage disease spread more effectively by improving diagnostic accuracy and speed.

Additionally, telemedicine applications powered by AI can transform healthcare delivery by enabling remote diagnosis and treatment. This is particularly critical in rural or remote areas, where AI-assisted telemedicine platforms can facilitate consultations with specialists located in urban centers, thereby bridging the gap in medical service delivery. AI can also assist in continuous patient monitoring through wearable health devices that track vital signs and alert medical staff about potential health issues before they become critical, ensuring timely medical intervention. Fig. 3 shows the applications of AI in different aspects of healthcare.

However, the deployment of AI in healthcare does not come without challenges. One major concern is the privacy and security of sensitive health data (Villegas-Ch & García-Ortiz, 2023). As healthcare systems

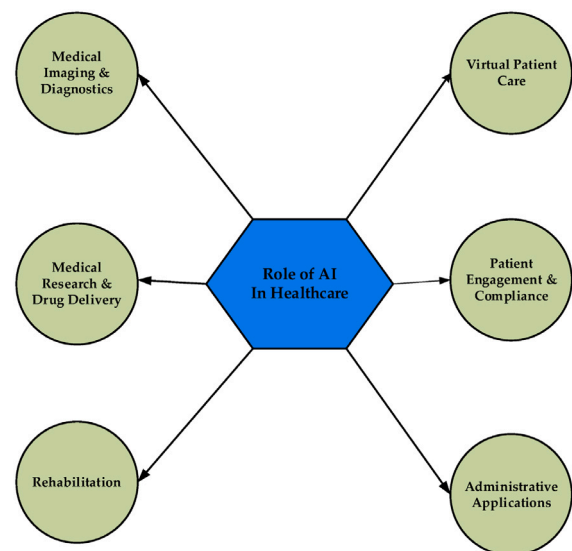


Fig. 3. Applications of AI in Healthcare (AI Kuwaiti et al., 2023).

collect and process large volumes of personal data, ensuring the integrity and confidentiality of this data is paramount. AI systems must be designed with robust cybersecurity measures to protect against data breaches and ensure compliance with medical confidentiality regulations (Sallstrom et al., 2019). Additionally, infrastructural limitations pose significant challenges to widespread AI adoption. In many parts of Africa, inconsistent electricity supply, inadequate internet connectivity, and the lack of modern medical equipment can hinder the effective deployment of AI technologies. To overcome these barriers, investments in infrastructure are essential, along with the development of AI solutions that can operate effectively in low-resource settings.

There is also a pressing need for training healthcare providers to effectively use AI technologies. This includes technical training and education on the ethical implications of AI in medicine. Healthcare professionals must be equipped with the knowledge and skills to integrate AI tools into their practice responsibly and effectively.

5.2. AI and agriculture

The agricultural sector in Africa stands to gain significantly from advancements in AI (Gikunda, 2024; Ly, 2021; Olivier & Ibrahim, 2024). AI-driven precision farming and disease prediction technologies can transform traditional farming into a more efficient, sustainable, and productive industry. These technologies leverage a combination of sensors, drones, and data analytics to monitor crop health, analyze soil conditions, and manage agricultural resources with unprecedented precision (Javaid et al., 2023). Precision farming, one of the primary applications of AI in agriculture, utilizes sensors and satellite imagery to gather real-time data about the condition of crops and soil. These sensors provide valuable metrics such as moisture levels, nutrient status, and more (Khanal, Kc, Fulton, Shearer, & Ozkan, 2020). AI algorithms then process this data to make informed decisions about watering schedules, fertilization, and even harvesting times, thus optimizing agricultural operations and significantly enhancing crop yield and quality.

Furthermore, AI-enabled drones can conduct regular aerial surveys of farmland to detect early signs of disease, pest infestation, or nutrient deficiency (Shaikh et al., 2022). Early detection would allow farmers to react swiftly, applying targeted treatments that minimize crop damage and reduce chemical use, thereby lowering production costs and environmental impact (Javaid et al., 2023). For example, AI systems can identify specific areas of a field that are affected by pests and

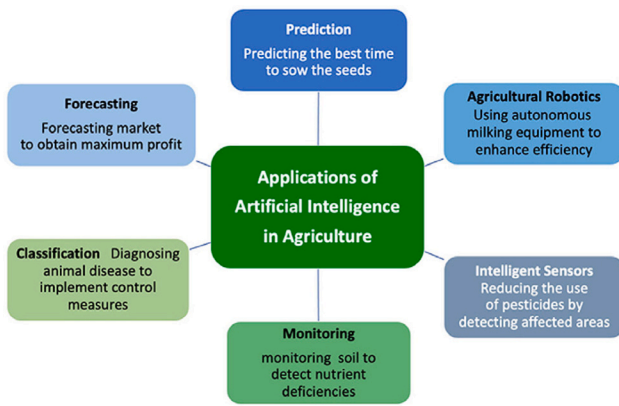


Fig. 4. Applications of AI in Agriculture (Dara, Hazrati Fard, & Kaur, 2022).

direct localized pesticide application, rather than blanket treatment. This precision can save costs and also mitigates the adverse effects of pesticides on the ecosystem.

However, the integration of AI into African agriculture faces several substantial challenges. The high cost of AI technologies remains a significant barrier for many small to medium-sized farms, which constitute the majority of Africa's agricultural landscape (Da Silva, Da Silva, Machado, Barbedo, & Amaral, 2023; Jayne, Chamberlin, & Benfica, 2018). The initial investment in AI technology, including sensors, drones, and data processing capabilities, can be prohibitively expensive for smallholder farmers. Additionally, the diversity of agricultural contexts across Africa — from arid regions to tropical climates — necessitates the local adaptation of AI systems. AI models trained in one geographical area may not perform well in another without significant reconfiguration and local calibration. This requires technical expertise and a deep understanding of local agricultural practices and conditions. There is also a need for training and capacity building among farmers and agricultural workers. Familiarity with AI tools and the ability to interpret AI-generated insights correctly is crucial for these technologies to be effectively implemented. Education and training programs must be expanded to ensure that the workforce can adapt to and embrace these new technologies.

Furthermore, the potential applications of AI in agriculture are enormous, and Fig. 4 shows some of these applications.

5.3. AI and education

Education represents a crucial area where AI can drive substantial change, especially in Africa, where access to quality education can be uneven (Arakpogun, Elsañ, Olan, & Elsañ, 2021; Goralski & Tan, 2023). AI technologies can enhance educational experiences through personalized learning and language translation, offering scalable solutions that can address some of the systemic challenges in education systems across the continent. Personalized learning, facilitated by AI, adjusts the pace and content of instruction based on individual learner profiles and feedback (Lee, Huh, Lin, & Reigeluth, 2018). AI systems can tailor educational materials and assessments to suit each student's unique needs by analyzing data on students' performance and learning habits, thereby maximizing learner engagement and effectiveness (Gligorea et al., 2023). This approach can assist students who struggle to keep up but also challenges those who are ahead, ensuring that every student can achieve their potential.

Meanwhile, AI has the power to overcome language barriers that are prominent in Africa's multilingual landscapes. AI-driven language translation tools can enable the conversion of educational content into numerous local languages, making learning more accessible and inclusive. This is particularly transformative in regions where educational resources in indigenous languages are scarce or nonexistent.

Furthermore, recent studies have identified that the potential for AI in education could extend to more advanced applications such as virtual tutors and AI-enhanced immersive experiences using augmented and virtual reality (Dai & Ke, 2022; Papakostas, Troussas, & Sgouropoulou, 2024). These technologies could provide highly engaging, interactive learning environments that simulate real-world scenarios or historical events, making learning more vivid and experiential.

Despite these advantages, the integration of AI in education faces significant challenges. The digital divide remains a barrier; many areas in Africa lack the necessary digital infrastructure, such as reliable internet access and modern computing devices, which are crucial for implementing AI-based educational tools. Without equitable access to these technologies, there is a risk that AI could widen existing educational disparities rather than close them. Additionally, there is an urgent need for curricula that include AI literacy. As AI becomes more integral to various aspects of life and work, students must be equipped to use AI tools and also to understand and critically engage with these technologies. This includes teaching skills related to AI ethics, data privacy, and the societal impacts of automation and AI technologies. Lastly, to fully realize AI's potential in transforming education in Africa, stakeholders — including governments, educational institutions, and technology firms — must collaborate to address infrastructural deficits and promote digital equity. Policy frameworks should also support innovation in educational technologies while safeguarding against potential misuse of AI.

5.4. AI and environmental protection

AI has significant potential in the environmental protection domain, providing tools that can enhance our understanding and stewardship of natural resources. In Africa, where environmental challenges are stark and diverse, from deforestation and desertification to wildlife conservation and water management, AI can play a crucial role in both monitoring and mitigating environmental threats. AI's capability to process vast amounts of environmental data rapidly and with high precision is particularly valuable (Cowls, Tsamados, Taddeo, & Floridi, 2021). For instance, ML algorithms can be used to analyze satellite imagery and aerial photographs to monitor changes in land use, track deforestation rates, and identify illegal logging activities (Nguyen, Sophea, Gheewala, Rattanakom, Areerob, & Prueksakorn, 2021). This real-time monitoring enables quicker responses and more effective resource management. Similarly, AI-driven systems can be employed to track wildlife movements and populations, helping to combat poaching and trafficking by predicting poacher behaviors and suggesting optimal patrol routes for rangers.

Beyond monitoring, AI can also assist in managing natural resources more sustainably. Through predictive analytics, AI can forecast climate-related events such as droughts and floods with greater accuracy, allowing for better preparedness and response strategies (Singh & Goyal, 2023). These capabilities are crucial for adapting to climate change, particularly in regions that are highly vulnerable to its impacts. AI's integration into urban planning is another area of promise. Smart city solutions that incorporate AI can optimize energy use, reduce waste, and decrease the carbon footprint of cities (Chui, Lytras, & Visvizi, 2018). For example, AI can be integrated into the energy grids to enhance the efficiency of power distribution and usage, significantly reducing energy wastage. Additionally, AI can help design green buildings and sustainable infrastructure by simulating various environmental impacts and energy consumption scenarios.

However, robust data collection systems are essential for AI to be effective, requiring extensive sensor networks and satellites that continuously gather accurate and comprehensive environmental data. Establishing such systems in Africa can be difficult due to financial, technological, and logistical constraints. Moreover, significant processing power is needed to analyze the collected data, which can be a barrier in regions with limited computing infrastructure. Overcoming these challenges often requires substantial investment in technology and infrastructure, as well as collaboration across governments, NGOs, and the private sector.

Table 3
Summary of AI applications and potential impacts in Africa.

Domain	AI application	Impact
Healthcare	Telemedicine	Increases access to medical services, especially in remote areas.
	Automated Diagnostics	Enhances detection and treatment of diseases like tuberculosis and malaria.
	Patient Monitoring	Enables early detection of potential health issues through real-time monitoring.
Agriculture	Precision Farming	Enhances crop yields and optimizes resource use.
	Disease Prediction	Enables early detection and precise treatment of crop diseases and pests.
Education	Personalized Learning	Tailors education to individual student needs, enhancing engagement.
	Language Translation	Makes educational content accessible in multiple languages.
Environmental Protection	Climate Prediction	Improves readiness and response to climate variability.
	Wildlife Monitoring	Aids in monitoring and protecting biodiversity.

5.5. AI and industry, innovation, and infrastructure

AI has been instrumental in driving industrial development globally, spurring innovation, and upgrading infrastructure. African economies can achieve enhanced productivity and sustainability by integrating AI into various sectors, positioning themselves more competitively in the global market. AI's impact on industry is enormous, particularly in manufacturing (Makridakis, 2017). Smart manufacturing systems that incorporate AI can monitor production processes in real-time, optimizing efficiency and reducing waste (Ding et al., 2020; Qu, Ming, Liu, Zhang, & Hou, 2019). AI algorithms analyze data from the production line to predict equipment failures before they occur, scheduling maintenance that minimizes downtime and extends the lifespan of machinery. This predictive maintenance is essential for industries that rely on high capital investments in equipment.

In addition to improving manufacturing processes, AI can play a crucial role in revolutionizing supply chain management. AI systems can forecast demand more accurately, optimize logistics and delivery routes, and manage inventory more effectively (Helo & Hao, 2021). This leads to reduced operational costs and improved customer satisfaction. For example, AI can suggest the most efficient shipping routes based on weather conditions, traffic patterns, and vehicle health, significantly reducing fuel consumption and delivery times. Moreover, AI contributes to infrastructure development by enhancing the design and operation of critical systems such as transportation networks, electrical grids, and water supply systems. In urban areas, AI can help manage traffic flows, reducing congestion and pollution levels. AI-enhanced smart grids can dynamically balance energy supply and demand, incorporating renewable energy sources more effectively and ensuring more stable and sustainable energy systems (Saberikamarposhti et al., 2024) (see Table 3).

Across all these sectors, the impact of AI can be profound if the challenges are adequately addressed. Key success factors include strong policy frameworks, investments in AI research and infrastructure, partnerships between public and private sectors, and community engagement to ensure that AI solutions are tailored to local needs and conditions. By overcoming these challenges, AI can significantly contribute to achieving the Sustainable Development Goals in Africa, driving progress that is both inclusive and sustainable.

6. Strategies for optimizing AI for sustainable development in Africa

To maximize the benefits of AI for sustainable development, strategic approaches must be implemented that consider the unique challenges and opportunities in Africa. These challenges include inadequate infrastructure, limited access to technology in rural areas, a scarcity of skilled professionals, and significant gaps in regulatory frameworks, which can hinder the effective deployment of AI technologies. These strategies should focus on enhancing the efficiency and reach of AI technologies in sectors critical to development, such as healthcare, agriculture, education, environmental protection, and industry. This section outlines key strategies to effectively utilize AI technologies to achieve the SDGs and addresses the necessary adaptations to overcome existing barriers.

6.1. Building infrastructure and connectivity

Effective implementation of AI technologies heavily relies on the foundational aspect of strong infrastructure and widespread connectivity (Gill et al., 2022). In many parts of Africa, inconsistent electricity supply and inadequate internet connectivity hinder the effective deployment of AI technologies. This section discusses the critical requirements and strategic approaches to building the necessary digital and power infrastructure to facilitate AI applications in sustainable development.

6.1.1. Enhancing digital infrastructure:

Robust digital infrastructure is the backbone of successful AI deployment (Gill et al., 2022; Hinson, Lensink, & Mueller, 2019). To this end, significant efforts must be directed towards expanding internet access across Africa, particularly focusing on rural and traditionally underserved areas where digital divide issues are most pronounced. This involves laying down physical broadband networks and promoting affordable wireless connectivity solutions to increase internet penetration rates. Additionally, the development of local data centres is critical for reducing data latency and improving the efficiency of AI systems. Local data centres ensure that large datasets, which are fundamental to AI operations, can be processed closer to where they are generated, thus enhancing the speed and responsiveness of AI applications. Governments and private entities should collaborate to fund and build these facilities, leveraging advances in green data centre technologies to minimize environmental impacts.

6.1.2. Reliable power supply:

AI technologies require continuous and reliable electricity to function effectively, making the power supply a vital area of focus (Sarker, 2022). In regions where power interruptions are common, the unreliability can hinder the use and scalability of AI solutions. To address this, investments in renewable energy sources such as solar, wind, and hydroelectric power are essential. These sources provide more stable power and also align with the sustainable development goals by reducing reliance on fossil fuels and minimizing carbon footprints. The integration of smart grids equipped with AI technologies can further enhance power management efficiency. Smart grids aid in predicting energy demand fluctuations and optimizing electricity distribution, which is crucial for maintaining the stability of power systems, especially in areas where energy generation is diversifying and decentralizing.

6.2. Developing human capital and AI literacy

The successful implementation and integration of AI technologies in sustainable development critically depend on the availability of skilled human capital and widespread AI literacy. Currently, there is a significant shortage of AI training and education, which limits the local capacity to develop and maintain AI systems. Therefore, strategic initiatives focusing on education, training, and public awareness are essential.

6.2.1. Education and training programs

Developing human capital in AI and data science requires a comprehensive approach to education and training. Integrating AI into educational curricula at all levels, including primary schools up to tertiary institutions, ensures that upcoming generations are well-versed in the fundamentals of AI and prepared for future careers in this field (Southworth et al., 2023). Such integration involves theoretical and practical learning and hands-on experience with AI tools and systems. Furthermore, vocational training programs are crucial for the existing workforce. These programs should be designed to upskill workers, particularly in industries most likely to be transformed by AI, such as manufacturing, healthcare, and agriculture. Upskilling initiatives can include short courses, workshops, and certification programs that focus on AI applications relevant to specific sectors.

6.2.2. Public awareness campaigns

Public perceptions of AI significantly influence the technology's acceptance and adoption. To cultivate a supportive environment for AI, it is imperative to increase the general public's understanding through targeted awareness campaigns (Ahn & Chen, 2022; Gerlich, 2023). These campaigns can demystify AI technologies by explaining their benefits, addressing common misconceptions, and highlighting successful case studies where AI has positively impacted communities. Such campaigns should utilize diverse media platforms, including television, radio, social media, and community workshops, to reach a broad audience. Special emphasis should be placed on illustrating how AI can be a tool for social good, improving everyday life by enhancing services such as healthcare, education, and public safety. Making AI more relatable and less intimidating can enable a more informed public discourse about AI's role in society and encourage more individuals to engage with and benefit from AI technologies.

6.3. Promoting innovation and research

Innovation and research are critical drivers of AI advancement and are necessary to ensure that AI technologies are effectively tailored to meet local needs in Africa. To promote a culture of innovation and support the development of relevant AI solutions, a focused approach to nurturing local research and establishing supportive ecosystems is essential.

6.3.1. Supporting local AI research

Supporting local AI research involves providing funding and ensuring that researchers have access to necessary data and computing resources. Governments and private sector partners can collaborate to fund AI research initiatives, focusing on practical applications that address specific regional challenges. In addition to financial support, creating partnerships with international research institutions can provide local researchers with access to cutting-edge knowledge and technologies (Cai, Ramis Ferrer, & Luis Martinez Lastra, 2019; Ho et al., 2023). This can enhance the quality of research outputs and ensure that local solutions benefit from global advancements in AI. Encouraging universities and other academic institutions to prioritize AI research and its applications in their curricula and projects can also stimulate a continuous supply of innovative ideas and skilled graduates ready to contribute to the AI sector.

6.3.2. Innovation hubs and incubators

Innovation hubs and incubators are instrumental in cultivating an environment that nurtures talent and entrepreneurship in the AI field. By providing startups and individual innovators with workspace, mentoring, and access to investors, these hubs can accelerate the development of AI applications that are commercially viable and socially beneficial. These hubs often act as a bridge between academic research and commercial markets, helping to translate academic innovations into market-ready products and services. Innovation hubs enable knowledge

exchange and networking among AI professionals by encouraging a collaborative environment, which can lead to enhanced innovation and more rapid problem-solving (Amann, Granström, Frishammar, & Elfsberg, 2022). Furthermore, incubators can play a crucial role in providing early-stage AI startups with the guidance and resources they need to navigate the complexities of the technology landscape. This includes legal advice, business training, and technical support, which are crucial for young companies looking to make a mark in the competitive field of AI.

Ensuring a vibrant ecosystem for AI innovation and research requires committed involvement from multiple stakeholders, including governments, academia, industry, and the international community. Through supporting local research and establishing innovation hubs, Africa can develop AI solutions that are not only innovative but also aligned with its unique cultural, economic, and social contexts. This proactive approach to nurturing and investing in local talent and ideas is essential for realizing the potential of AI in driving sustainable development across the continent.

6.4. Regulatory frameworks and ethics

Establishing robust regulatory frameworks and ethical guidelines is crucial for the responsible development and deployment of AI technologies. As AI continues to integrate into various sectors, ensuring that these technologies are used safely, fairly, and without infringing on individual rights is paramount.

6.4.1. Developing AI policies and regulations

To harness the benefits of AI while mitigating potential harms, clear and comprehensive AI policies and regulations must be established. These policies should govern how AI systems are developed, deployed, and used within society (Olorunfemi et al., 2024). They need to address a range of issues, including but not limited to data protection, intellectual property rights, transparency, accountability, and inclusivity. The formulation of these policies should involve a wide array of stakeholders, including policymakers, technologists, legal experts, and representatives from civil society, to ensure that diverse perspectives are considered (Sallstrom et al., 2019). For instance, regulations can mandate that AI systems undergo rigorous testing and validation before deployment to ensure they do not perpetuate existing biases or lead to new forms of discrimination. Similarly, policies should require that AI systems be transparent and explainable, meaning that decisions made by AI can be understood and contested by humans (Caton & Haas, 2020; Mehrabi, Morstatter, Saxena, Lerman, & Galstyan, 2021). Additionally, cross-border cooperation can be crucial, especially given the global nature of data flows and AI technologies. Harmonizing regulations across different jurisdictions can help manage the challenges of AI governance on a larger scale, facilitating international collaboration and reducing the complexity for entities that operate across multiple countries.

6.4.2. Ethical guidelines

Beyond formal regulations, adopting ethical guidelines is essential to ensure AI technologies promote the public good and do no harm. These guidelines should emphasize principles such as fairness, accountability, transparency, and respect for user privacy (Singhal et al., 2024; Wu, 2024). Ethical AI practices encourage trust among the general public and stakeholders by ensuring that AI systems operate in a manner that is consistent with societal values and legal norms (Felzmann, Fosch-Villaronga, Lutz, & Tamò-Larrieux, 2020; Jobin, Ienca, & Vayena, 2019; Mary, Calauzenes, & El Karoui, 2019). Ethical guidelines can also guide AI developers and users in navigating complex moral dilemmas that might arise from AI deployment. For example, guidelines could provide frameworks for addressing issues related to the potential displacement of jobs due to AI automation, ensuring there are strategies in place for workforce retraining and social safety nets. Furthermore,

ethics in AI should address the importance of including diverse datasets and perspectives in the development of AI systems to avoid biases that could lead to unfair treatment of certain groups. Ensuring that AI development is inclusive and equitable will help prevent the reinforcement of social inequalities through technology.

6.5. Partnerships and collaborations

The complexity of implementing AI technologies for sustainable development necessitates broad and effective partnerships and collaborations. These relationships can facilitate resource sharing and also enhance innovation through diverse expertise. Strengthening both international cooperation and public-private partnerships can significantly contribute to the success of AI projects by leveraging combined strengths and mitigating common challenges.

6.5.1. Strengthening international cooperation

International cooperation is crucial in the advancement of AI technologies. Collaborating with international partners can provide access to a wealth of knowledge, advanced technology, and additional funding sources that might not be readily available domestically (Erdélyi & Goldsmith, 2018). Such partnerships can be especially beneficial for countries in the Global South, as they can tap into the research and development advancements made by more technologically advanced nations. International collaborations can also help standardize AI practices and policies across borders, which is crucial given the global nature of data and technology. These cooperations can take various forms, including joint research projects, technology transfer agreements, and multinational policy frameworks.

6.5.2. Public-private partnerships

Public-private partnerships (PPPs) are essential for pooling resources and expertise to drive AI initiatives. These partnerships involve collaboration among governments, private sector entities, academic institutions, and non-governmental organizations (NGOs). Each partner brings unique strengths: governments can provide regulatory support and funding, private companies offer technological expertise and innovation, universities contribute to research and development capabilities, and NGOs can ensure that projects address the real needs of communities and adhere to ethical standards (Yerlikaya & Erzurumlu, 2021). PPPs can accelerate the development and deployment of AI solutions by facilitating investment in necessary infrastructure, research, and human capital development. For example, a government might partner with a technology firm to develop AI-driven health diagnostics tools, with a university providing the research base and an NGO ensuring the solutions reach underserved populations. These partnerships can enhance the efficiency and reach of AI projects and also ensure they are aligned with public goals and are sustainably integrated into local contexts.

6.6. Monitoring and evaluation

Effective monitoring and evaluation are critical to the success and sustainability of AI projects. These processes ensure that AI initiatives remain aligned with their intended goals and can adapt to changing conditions and feedback (Holzinger, Keiblinger, Holub, Zatloukal, & Müller, 2023; Perifanis & Kitsios, 2023). Firstly, continuous monitoring is crucial for ensuring that the projects contribute positively towards the SQGs and do not deviate from their set objectives. Monitoring should encompass various dimensions of the project, including technical performance, user engagement, socio-economic impacts, and environmental effects. Implementing robust monitoring mechanisms often requires the integration of data analytics tools that can process large volumes of data generated by AI systems. These tools assist in identifying patterns, trends, and anomalies that may indicate areas where the project is performing well or where it might be falling

short (Ginart, Jinye Zhang, & Zou, 2022; Quiñones-Grueiro, Prieto-Moreno, Verde, & Llanes-Santiago, 2019). For instance, in an AI-driven agricultural project, continuous monitoring could involve analyzing crop yield data over time to assess whether AI interventions are leading to sustainable improvements.

Secondly, the ability to adapt strategies based on monitoring feedback and project outcomes is essential for the resilience and relevance of AI projects. Adaptive strategies involve making informed adjustments to the project's methods, targets, or scope in response to new evidence or changing circumstances. Adopting an adaptive approach allows project managers to refine AI applications, optimize resource allocation, and mitigate any emerging risks or unintended consequences. This flexibility is particularly important in the fast-evolving field of AI, where technological advancements and societal dynamics can quickly alter the landscape in which AI solutions operate (Díaz-Rodríguez, Del Ser, Coeckelbergh, López de Prado, Herrera-Viedma, & Herrera, 2023; Kar, Varsha, & Rajan, 2023). For example, if an AI-enabled health diagnostics tool is found to have lower accuracy in certain populations due to biases in training data, an adaptive strategy would involve retraining the model with more representative data or adjusting the algorithm to correct these biases. This ensures that the model remains effective and equitable across different user groups. Moreover, adaptive strategies encourage innovation and continuous improvement, which are vital for maintaining the effectiveness of AI projects in a dynamic world. They enable project teams to experiment with new ideas and technologies, learn from their experiences, and systematically incorporate lessons learned into future project phases (see Table 4).

7. Proposed framework for AI integration in Africa's sustainable development

To maximize the potential of AI in accelerating sustainable development in Africa, we propose a conceptual framework based on five key pillars: Infrastructure, Human Capital, Innovation, Policy and Governance, and Partnerships. This framework provides a guiding structure for practitioners and policymakers, focusing on the essential areas that must be developed to ensure AI technologies are effectively deployed across various sectors. Rather than emphasizing immediate strategies, this framework is meant to inform long-term planning and policy development to align AI efforts with Africa's SDGs.

7.1. Infrastructure

The foundational pillar of AI-driven development is robust and reliable infrastructure. While strategies have already been discussed for immediate improvements, this pillar emphasizes the need for long-term planning and investments. African countries must prioritize expanding digital infrastructure, particularly in rural areas, and improving electricity reliability through renewable energy sources. These initiatives are crucial for enabling the continuous data processing and real-time information access that AI technologies require. Long-term investment in local data centers and green energy sources will further strengthen AI systems' operational sustainability.

7.2. Human capital and capacity building

The successful deployment of AI technologies requires a well-trained workforce capable of developing and maintaining AI systems. In addition to immediate educational reforms and training programs, this framework proposes that Africa's long-term success in AI will depend on a sustainable pipeline of AI talent. This can be achieved by integrating AI literacy into primary, secondary, and tertiary education systems, ensuring that the next generation is equipped with the necessary skills. Upskilling programs for current professionals must be aligned with emerging AI technologies and tailored to the unique socio-economic context of each country.

Table 4
Strategies for optimizing AI for sustainable development in Africa.

Strategy area	Focus	Description
Infrastructure and Connectivity	Enhancing Digital Infrastructure Reliable Power Supply	Expanding internet access and constructing local data centers to improve AI response times. Using renewable sources to ensure stable power for AI operations.
Human Capital and AI Literacy	Education and Training Programs Public Awareness Campaigns	Integrating AI education into all educational levels to prepare a future-ready workforce. Conducting campaigns to enhance public understanding and support for AI.
Innovation and Research	Supporting Local Research Innovation Hubs and Incubators	Allocating funds and resources for developing AI solutions tailored to local needs. Establishing support environments for AI startups and academic collaborations.
Regulatory and Ethics	AI Policies and Regulations Ethical Guidelines	Developing comprehensive policies for ethical AI use, ensuring transparency and privacy. Setting ethical standards to guide responsible AI deployment and usage.
Partnerships and Collaborations	International Cooperation Public-Private Partnerships	Building partnerships to leverage global AI knowledge and resources. Cultivating cross-sector collaborations to boost AI project efficacy.
Monitoring and Evaluation	Continuous Monitoring Adaptive Strategies	Implementing systems to continuously assess and report on AI impacts. Adapting project strategies dynamically to optimize results and incorporate feedback.

7.3. Innovation and research

Innovation and research will serve as the driving force behind AI's transformative potential in Africa. This pillar focuses on enabling research and development initiatives that align AI technologies with Africa's specific challenges. Establishing innovation hubs, incubators, and research institutions dedicated to AI will not only encourage local talent but also ensure that AI solutions are designed with local contexts in mind. By prioritizing local research, African countries can develop solutions that address sector-specific needs such as healthcare, agriculture, and environmental conservation.

7.4. Policy and governance

Sound regulatory frameworks and ethical guidelines are vital to ensuring that AI is implemented in a transparent and accountable manner. Building on the need for immediate regulatory efforts, this pillar emphasizes long-term policy development that can evolve alongside technological advancements. Governments should focus on creating flexible policies that balance innovation with societal needs. This includes ensuring data privacy, minimizing bias in AI algorithms, and ensuring inclusive AI development that benefits all socio-economic groups. Additionally, cross-border harmonization of AI policies across African nations will be essential for facilitating large-scale, continent-wide AI deployments.

7.5. Partnerships and collaborations

No single entity can drive AI-enabled sustainable development alone. As previously discussed in Section 6, partnerships between governments, private sectors, academia, and non-governmental organizations (NGOs) are crucial. This framework extends that notion, emphasizing the need for long-term partnerships that align with Africa's SDGs. International collaborations with technologically advanced countries can bring valuable technical expertise and funding, while public-private partnerships will ensure that AI solutions are financially sustainable and scalable.

7.6. Operationalizing the framework

To bring the framework to life, African governments, institutions, and industries must focus on aligning AI applications with specific SDG targets. For example, AI can significantly improve healthcare outcomes (SDG 3: Good Health and Well-being) through remote diagnostics and personalized treatment systems. Similarly, AI can enhance food security (SDG 2: Zero Hunger) by optimizing agricultural productivity and resource management. Meanwhile, this framework serves as a strategic roadmap, offering a long-term vision for integrating AI technologies into Africa's development agenda.

8. Discussion and future research directions

Initial efforts on the integration of AI into sustainable development initiatives across Africa have predominantly focused on developing and deploying AI technologies to address immediate needs in sectors such as healthcare, agriculture, and environmental protection. However, to harness the full potential of AI, more comprehensive studies are needed to understand its long-term impacts on economic stability and social inequality. Therefore, future research could explore the scalability of successful pilot projects to broader applications across different regions of the continent.

Moreover, interdisciplinary research is essential to bridge the gap between AI technology and its practical implications. This involves collaborations between computer scientists, economists, sociologists, and environmental scientists to create holistic solutions that are both technologically sound and culturally relevant. For instance, integrating indigenous knowledge systems with AI-based models could lead to innovations that are uniquely suited to local challenges, thereby enhancing community acceptance and effectiveness.

Another critical area for future research is the development of robust AI systems that operate reliably in diverse African environments. These systems must be resilient to the infrastructural limitations prevalent in many parts of Africa, such as intermittent internet and electricity. Research into low-resource AI solutions that can function effectively under these constraints will be vital. Such studies will not only improve the reliability of AI applications but also make them more accessible to underserved populations.

Finally, the success of AI initiatives relies heavily on continuous monitoring and evaluation to assess their impact and sustainability. Future research could, therefore, develop advanced analytical tools and methodologies to measure the effectiveness of AI technologies in real-time. By providing timely insights into the performance of AI applications, researchers can assist policymakers and practitioners refine their strategies, ensuring that AI continues to contribute positively to sustainable development goals in Africa.

9. Conclusion

AI has demonstrated significant potential to advance sustainable development across various sectors in Africa, including healthcare, agriculture, education, and environmental protection. This paper has explored the integration of AI to address Africa's unique challenges, providing strategic insights for enhancing infrastructure, developing human capital, driving innovation, and ensuring ethical governance. The proposed strategies emphasize the need for a strong digital infrastructure, upskilling local talent, and enabling an inclusive regulatory environment to ensure that AI can be effectively employed for sustainable development. These approaches, if carefully implemented, can help Africa overcome its socio-economic and environmental challenges, bringing AI's full transformative potential to life. In practice,

successful implementation of these strategies will require cross-sector collaboration, government support, and partnerships between local and international stakeholders. AI solutions that are locally adapted will not only promote economic development but also contribute to social equity and environmental sustainability.

However, this study acknowledges certain limitations. The scope of this review is largely based on existing literature and may not capture the full extent of emerging AI innovations or regional variations across Africa. Additionally, infrastructural and regulatory gaps pose significant challenges that this study has not fully addressed, indicating the need for continued research, particularly in developing low-resource AI systems that are accessible to all communities. Finally, this paper aims to serve as a resource for AI researchers, policymakers, and industry professionals, encouraging collaborative efforts to realize the transformative power of AI in achieving the SDGs in Africa. The insights provided here offer a framework that can guide future research and practical applications, helping AI contribute meaningfully to Africa's sustainable growth.

CRedit authorship contribution statement

Ibomoiye Domor Mienye: Conceptualization, Methodology, Software, Writing – original draft, Writing – review & editing. **Yanxia Sun:** Conceptualization, Funding acquisition, Supervision, Validation, Visualization, Writing – review & editing. **Emmanuel Ileberi:** Conceptualization, Methodology, Software, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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