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Optimizing the readiness for industry 4.0 in fulfilling the Sustainable Development Goal 1: focus on poverty elimination in Africa

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This study explores the transformative potential of fourth industrial revolution (called Industry 4.0) technologies in the context of poverty elimination, with a particular focus on Africa. Given the multidimensional nature of poverty, which spans economic, social, and environmental aspects, there is a critical need for innovative and sustainable solutions. This paper presents a comprehensive literature review to identify how recent advancements, such as artificial intelligence (AI), the Internet of Things (IoT), robotics, blockchain, big data, and 5G can be harnessed to address various facets of poverty. Drawing on insights from existing research and expert opinions, we propose a conceptual framework that integrates these technologies with strategic policy interventions, infrastructure development, and capacity building. The paper proposes a framework that illustrates the prerequisite requirements before adopting Industry 4.0 technologies in poverty elimination efforts. This framework aims to ensure that the benefits of technological innovations are accessible to the most vulnerable populations, thereby contributing to the broader goals of socioeconomic development and poverty reduction. The work shows that while Industry 4.0 presents a critical opportunity for sustainable development and poverty elimination in Africa, it needs to have essential capacities to optimize the use of observations, visualizations, and mindset management before or when adopting the first stage of Industry 4.0 solutions for poverty elimination.

KEYWORDS

fourth industrial revolution, digitalization, artificial intelligence, internet of things, sustainability, socioeconomic development, precision poverty alleviation, digital innovations

1 Introduction

The world continues to grapple with the challenge of poverty elimination, a critical issue intertwined with eradicating hunger, addressing climate change, and solving other complex socioeconomic problems. These challenges necessitate creative and innovative solutions that are not only effective but also sustainable. It is crucial that these solutions promote economic growth, social inclusion, and environmental sustainability, ensuring a holistic approach to development that meets present needs without compromising the ability of future generations

to meet their own (Buheji, 2019; Goralski and Tan, 2022; Tang, 2022). However, with the rise of conflicts and polarization around the world, coupled with resource limitations, the rapid increase in global population, the risk of new pandemics, and the growing number of dependents due to an aging population, as well as the increase in NEET youth (i.e., youth not in employment, education, or training), the need for innovative, sustainable, and mutually beneficial solutions has never been more critical. These solutions are essential to reducing poverty in developing countries, particularly in Africa (Buheji and Ahmed, 2019; Buheji, 2020b; Zervoudi, 2020; Rohr et al., 2023; Hassoun et al., 2024a).

Among the innovative solutions that have gained momentum over the past few years is the application of Fourth Industrial Revolution (Industry 4.0) technologies. The main Industry 4.0 enabling technologies are artificial intelligence (AI), the Internet of Things (IoT), blockchain, big data, smart sensors, cyber-physical systems, digital twins, robotics, 3D printing, and cybersecurity (Hassoun et al., 2023a, 2024b). Growing evidence shows that these technologies could provide promising opportunities in many sectors and fields, such as agriculture and food industry (Hassoun et al., 2023b, d, 2024c), supply chain management (Birkel and Müller, 2021), manufacturing sector (Raj et al., 2020), and applications in medical fields, such as fighting COVID-19 pandemic (Javaid et al., 2020), among others. The potential of Industry 4.0 to enhance sustainability and foster the achievement of sustainable development goals (SDGs) has been widely investigated (Bai et al., 2020; Ghobakhloo, 2020; Hassoun et al., 2022). Industry 4.0 technologies can revolutionize production processes, increase efficiency, and drive innovation, offering significant opportunities for economic growth and development. By leveraging these technologies, it is possible to create inclusive and sustainable solutions that address the multifaceted challenges of poverty and contribute to the broader goals of socioeconomic development.

While the potential of Industry 4.0 technologies to address poverty has been increasingly recognized, existing reviews have predominantly focused on specific technologies such as AI (Mhlanga, 2021; Goralski and Tan, 2022; Hassan et al., 2023) and fifth generation (5G) of wireless mobile networks (Cabanillas-Carbonell et al., 2023). To fully harness the benefits of Industry 4.0 for poverty reduction, it is imperative to expand the focus beyond AI and 5G, exploring and documenting the applications and impacts of a broader range of Industry 4.0 technologies. Thus, there remains a notable gap in the literature, as no comprehensive reviews have addressed the impact of other Industry 4.0 technologies, such as IoT, blockchain, robotics, among others, on poverty alleviation. These technologies hold immense potential to further drive economic growth and development in underserved areas, contributing to sustainable development and poverty alleviation efforts. Consequently, this study is pioneering in offering a comprehensive overview of how various Industry 4.0 technologies—such as AI, blockchain, big data, and IoT—are being utilized to reduce poverty.

This paper explores the transformative impact and potential of Industry 4.0 technologies in enhancing socioeconomic conditions, particularly focusing on alleviating poverty in Africa. The rest of this paper is organized as follows: In Section 2, we provide a general overview of Industry 4.0 technologies, while Section 3 presents essential data related to poverty elimination and achieving SDG 1. The methodology is detailed in Section 4, where we outline the data collection methods employed in the study. Section 5 offers examples of Industry 4.0 applications for poverty reduction, followed by a proposed framework for implementing these technologies in Africa in Section 6. Section 7 discusses the implications and limitations of the study, while Section 8 addresses future directions and conclusions.

2 Overview of industry 4.0 technologies

The fourth industrial revolution, known as Industry 4.0, holds significant potential due to the convergence between digital, physical, and biological advancements and technological innovations (Figure 1). The main digital technologies are AI, big data, and blockchain but other related technologies such as digital twins and 3D printing can be also considered under the digital pillar of Industry 4.0. Advanced technologies, such as smart sensors, IoT, and robotics and drones form the main physical component of Industry 4.0, while biological pilar of Industry 4.0 includes a wide range of biological innovations (such as precision fermentation and genome-editing techniques) and nanotechnological advancements.

These technologies foster enhanced connectivity, productivity, quality, and profitability throughout the supply chain, showcasing its critical role in tackling complex challenges (Abbate et al., 2023; Derakhti et al., 2023; Hassoun et al., 2023c, 2024d).

According to UNIDO (2020), the main technologies that can make Industry 4.0 work for Africa are AI, industrial IoT, big data, advanced robotics, additive manufacturing, and 5G connectivity (Figure 2). AI is one of the core technologies of Industry 4.0 that has been revolutionizing various aspects of our lives. A wide variety of AI-related methods and algorithms is recently being levered in various applications, including poverty prediction and elimination (Mhlanga, 2021; Usmanova et al., 2022). IoT and big data are also essential enablers for Industry 4.0 that allow advanced applications in multiple domains and disciplines (Liang and Wang, 2022; Zhang, 2022; Tamasiga et al., 2023). The role of automation and advanced robotics is being increasingly recognized, especially after the outbreak of COVID-19 that led many companies and individuals to embrace robots to address the challenges of the pandemic (Khamis et al., 2019; Zhao et al., 2021; Ross et al., 2022). The use of robots can speed up the progress towards achievement various SDGs, including zero poverty (Haidegger et al., 2023). Additive manufacturing, such as 3D printing is another emerging promising technology that has huge potential, especially when combined with other Industry 4.0 technologies, such as IoT, big data, and robotics, to transform and revolutionize production (Praveena et al., 2022). Regarding 5G connectivity, it is believed to bring about a major revolution, offering new possibilities for communication and access to information, accelerating poverty reduction, making a major contribution to the achievement of SDG1 (Cabanillas-Carbonell et al., 2023).

3 Eliminating poverty and achieving Sustainable Development Goal 1

3.1 General overview of SDG 1 and its relationship with other SDGs

SDG1 was established as part of the United Nations' 2030 Agenda for Sustainable Development in 2015. Its overarching aim is to eradicate poverty in all its forms everywhere by 20,230. This goal is
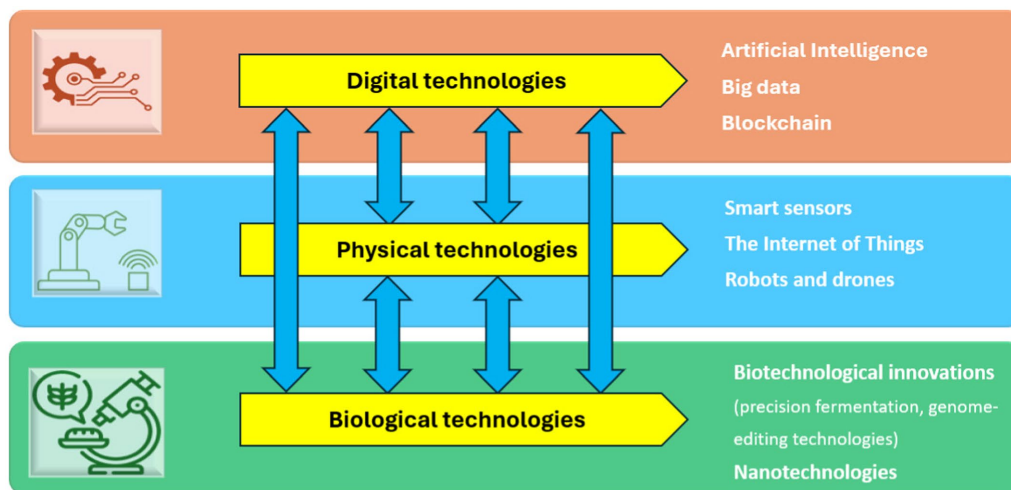
FIGURE 1
The main digital, physical, and biological technologies of Industry 4.0.
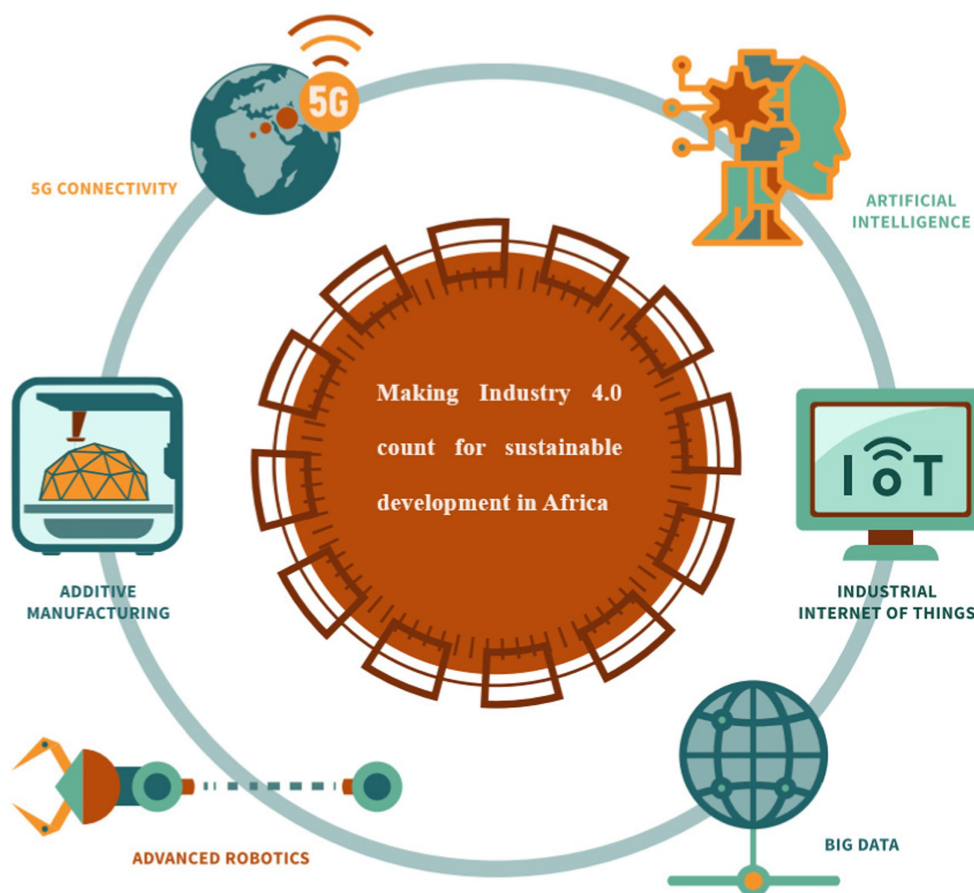
FIGURE 2
Industry 4.0 enabling technologies for digital transformation in Africa (Derived from UNIDO, 2020).

significant as it recognizes the multidimensional nature of poverty and aims to address various aspects such as social, economic, and environmental factors that contribute to poverty (Feliciano, 2019; Leal Filho et al., 2021).

SDG 1 encompasses several targets designed to achieve specific outcomes related to poverty eradication. Target 1.1 focuses on eradicating extreme poverty for all people everywhere, ensuring that no one lives on less than $1.9 a day. Meanwhile, Target 1.2 aims

to reduce poverty in all its forms by at least 50%, addressing various dimensions such as income, access to basic services, and social protection. Targets 1.3 and 1.4 aim to establish comprehensive social protection systems to support the poor and vulnerable, ensuring they have equal access to economic resources and essential services. Target 1.5 focuses on enhancing the resilience of the poor and those in vulnerable situations to climate-related extreme events and other economic, social, and environmental shocks and disasters. Lastly, Targets 1.a and 1.b emphasize the critical need to mobilize resources and establish robust policy frameworks to eradicate poverty (United Nations, 2015; Moyer and Hedden, 2020; Leal Filho et al., 2021).

To measure progress towards these targets, various indicators are employed. These include the proportion of the population living below the national and international poverty lines, the coverage of social protection systems, the access to basic services, and the extent of ownership and control over land and other forms of property by both men and women. These indicators provide a comprehensive assessment of poverty levels and the effectiveness of policies aimed at improving economic resources and social protection for vulnerable populations (Omomowo, 2018; Leal Filho et al., 2021). Additionally, indicators such as the number of deaths, missing persons, and directly affected persons attributed to disasters per 100,000 population, and the proportion of local governments that adopt and implement local disaster risk reduction strategies in line with national disaster risk reduction strategies, are used to measure progress towards building resilience and reducing vulnerability to climate-related extreme events and other economic, social, and environmental shocks and disasters (Chmutina et al., 2021).

It should be highlighted that although the poverty is mainly addressed in SDG 1, the achievement of this goal depends on the other goals as poverty eradication is foundational to achieving sustainable development (Feliciano, 2019; Leal Filho et al., 2021). For instance, SDG 2 (Zero Hunger) and SDG 3 (Good Health and Well-Being) directly benefit from poverty reduction, as improved economic conditions enable better access to nutritious food and healthcare. Education (SDG 4) and gender equality (SDG 5) are also closely tied to poverty alleviation, as financial stability provides greater opportunities for learning and empowerment. Access to clean water and sanitation (SDG 6) and clean energy (SDG 7) is often limited in the impoverished areas. Eradicating poverty can facilitate investments in water and renewable energy sources to improve infrastructure and services, ensuring that all individuals have access to these essential resources. Furthermore, SDG 8 (Decent Work and Economic Growth), SDG 9 (Industry, Innovation, and Infrastructure), SDG 10 (Reduced Inequalities), and SDG 11 (Sustainable Cities and Communities) emphasize the creation of sustainable infrastructure and industry as well as fair employment opportunities and equitable resource distribution, which are crucial for lifting people out of poverty.

SDG 1 is intrinsically linked to responsible consumption and production (SDG 12), climate action (SDG 13), life below water (SDG 14), life on land (SDG 15), peace, justice, and strong institutions (SDG 16), and partnerships for the goals (SDG 17). Indeed, eradicating poverty ensures sustainable consumption and production patterns by enabling resource-efficient and equitable growth. Climate action and environmental conservation are critical for protecting the livelihoods of impoverished communities who are most vulnerable to environmental degradation and climate change. Strong institutions and justice systems are essential for protecting the rights of the poor and ensuring equitable access to resources and opportunities. Finally, achieving SDG 1 requires robust partnerships at all levels, leveraging collective actions and resources to address the multifaceted nature of poverty and promote sustainable development.

3.2 Definition of poverty

Poverty is a multifaceted and intricate concept, with numerous definitions presented in the literature. Overall, poverty is characterized by a range of interrelated issues, including chronic hunger, malnutrition, poor health, and limited access to education and other essential services. It is often accompanied by increased morbidity and mortality rates, inadequate housing, and unsafe living conditions. Poverty also manifests in social exclusion, discrimination, and the lack of opportunities to participate in civil, social, and cultural life. These factors together highlight the multifaceted nature of poverty, emphasizing the need for comprehensive strategies to address its various dimensions. Thus, addressing poverty necessitates a multidisciplinary approach that considers all the aforementioned variables (Feliciano, 2019; Buheji, 2021; Kamruzzaman, 2021; Usmanova et al., 2022; Hassan et al., 2023).

Poverty is a multidimensional phenomenon resulting from a combination of various factors. Recognizing this complexity, the United Nations introduced the Multidimensional Poverty Index (MPI), which evaluates poverty through multiple indicators such as education, health, and living standards, among other variables. This approach highlights that poverty is not solely about insufficient income. The UN Development Programme (UNDP) underscores the importance of understanding poverty as encompassing a lack of access to health, education, and adequate living conditions. According to the UNDP's MPI, over 1.3 billion people were living in multidimensional poverty in 2021, facing deprivations across several aspects of their lives. This comprehensive perspective allows for more effective strategies to address the diverse and interconnected elements of poverty (Usmanova et al., 2022; He et al., 2023).

In the literature, two additional concepts related to poverty are frequently discussed: absolute poverty and overall poverty. Absolute poverty refers to the deprivation of basic human needs, such as food, shelter, safe drinking water, sanitation facilities, education, and access to information. This concept is about the minimum level of subsistence that individuals need to survive. On the other hand, overall poverty encompasses a broader range of deprivations, focusing on people's inability to access income and other productive resources that enable them to lead fulfilling lives. This includes not only basic needs but also access to opportunities that facilitate economic and social development (Mhlanga, 2021). Extreme poverty is defined as living in a condition of severe deprivation of basic human needs, which includes living below the International Poverty Line. This threshold was originally set at $1.90 per day but has recently been adjusted to $2.15 per day to account for changes in cost of living and inflation. Today, approximately 10% of the world's population lives in extreme poverty, facing substantial challenges in meeting their basic needs for survival and well-being (Kamruzzaman, 2021; Cabanillas-Carbonell et al., 2023; He et al., 2023).

3.3 Situation of poverty in Africa and globally

Poverty remains a significant global challenge, affecting millions of people worldwide. Inequality within and between countries significantly contributes to the persistence of poverty. Wealth is increasingly concentrated among the top echelons of society, while millions of people remain without access to basic services and opportunities for improvement. This growing disparity undermines social cohesion, economic stability, and the capacity of societies to effectively respond to crises (Wietzke, 2020). Climate change and environmental degradation disproportionately affect the world's poorest populations, who often lack the resources and infrastructure to adapt to changing environmental conditions. Droughts, floods, and extreme weather events can devastate livelihoods, particularly in agrarian communities and developing countries. These impacts exacerbate existing vulnerabilities and contribute to a cycle of poverty and environmental degradation. For example, the COVID-19 pandemic has had a profound impact on global poverty. It has reversed years of progress in poverty reduction, pushing millions of people into extreme poverty. The economic downturn caused by the pandemic has led to job losses, reduced income, and increased food insecurity, disproportionately affecting the poorest and most vulnerable populations (Leal Filho et al., 2021; Lakner et al., 2022; Saidi et al., 2023).

Despite significant progress in reducing global poverty over the past few decades, extreme poverty remains a pressing issue. Before the COVID-19 pandemic, the global poverty rate had been on a steady decline, with notable successes in countries like China and India significantly contributing to the reduction in global poverty. These countries implemented policies that spurred economic growth, improved access to education and healthcare, and expanded social protection programs, leading to substantial decreases in poverty levels. However, Sub-Saharan Africa has emerged as a region with the highest rates of extreme poverty and the fastest-growing population, presenting substantial challenges for poverty reduction efforts. The region's poverty rate has remained stubbornly high due to a combination of factors, including political instability, economic stagnation, limited access to education and healthcare, and frequent environmental shocks, such as droughts and floods (Wietzke, 2020; Saidi et al., 2023).

MPI remains persistently high in Africa, reflecting a combination of factors that contribute to poor health and inadequate living conditions. Many Africans suffer from poor health due to inadequate access to clean water, sanitation, nutritious food, and healthcare services. Diseases such as malaria, HIV/AIDS, and tuberculosis, along with high maternal and child mortality rates, significantly contribute to multidimensional poverty (Crespo Cuaresma et al., 2018; Atangana, 2022; Kakpo et al., 2022; Saidi et al., 2023).

Successful initiatives and case studies have demonstrated significant progress towards reducing poverty through targeted social protection programs, microfinance services, and disaster risk reduction strategies. One notable example is Bangladesh's "Challenging the Frontiers of Poverty Reduction" program. This initiative has significantly reduced poverty levels, especially in rural areas, by providing social safety nets and livelihood opportunities for the most vulnerable populations. The program includes cash transfers, food security measures, and skill development training, which have collectively helped lift many families out of poverty. In Rwanda, the government's efforts to promote financial inclusion and entrepreneurship have led to a notable reduction in poverty rates. The expansion of microfinance services has empowered individuals, particularly women, to start small businesses and improve their economic status. These services include access to small loans, savings accounts, and financial education, which have collectively contributed to economic empowerment and poverty reduction. The Philippines has made significant strides in mitigating the impact of natural disasters on vulnerable populations through community-based disaster risk reduction initiatives. These programs involve local communities in disaster preparedness and response planning, improving resilience and minimizing the economic and human toll of climate-related disasters (Carcellar et al., 2011; Cho and Kim, 2017; Nesa Hyder, 2020).

3.4 Learning from the Asian poverty elimination experience

Asian nations have utilized holistic approaches to tackle poverty, incorporating economic policies, social welfare programs, education and skill development initiatives, and technological innovations. The significant declines in poverty rates in countries such as China, Malaysia, India, Indonesia, Bangladesh, and other Southeast Asian nations provide valuable lessons for African countries (Asadullah et al., 2020; Buheji, 2020a).

Asian countries have effectively leveraged sustained economic growth to implement policies ensuring inclusivity and equal opportunities, significantly reducing poverty. They have heavily invested in education and healthcare, empowering individuals with the skills and well-being needed to fully participate in the economy. For example, China and India have undertaken extensive educational reforms and expanded healthcare access, leading to improved literacy rates and health outcomes (Dash, 2022). Technological advancements have also been pivotal in creating new employment opportunities, enhancing agricultural productivity, and delivering social services more efficiently. Indonesia has utilized digital platforms to improve agricultural practices, while South Korea has driven its manufacturing and service sectors through high-tech job creation (Obirikorang et al., 2021; Saleem et al., 2023).

Government-led initiatives, in collaboration with NGOs and the private sector, have expanded social safety nets, such as direct cash transfers and rural development projects. Malaysia's 1Malaysia People's Aid (BR1M) program provides direct financial assistance to low-income households, demonstrating the impact of such initiatives. Additionally, community-led efforts have engaged more people in poverty elimination strategies, ensuring that these strategies are tailored to local needs and conditions. Bangladesh's community-based approaches in poverty reduction programs exemplify the success of grassroots initiatives. These strategies offer valuable lessons for African countries (Gomez et al., 2021; Masud-All-Kamal and Nursey-Bray, 2021). By investing in education and healthcare, leveraging technology, fostering public–private partnerships, and encouraging community involvement, African nations can develop holistic approaches to poverty reduction. Adapting these proven methods to local contexts can help build a robust foundation for sustainable development and economic growth in Africa.

3.5 Challenges in eliminating multidimensional poverty

Eliminating poverty presents a complex array of multidimensional and interconnected challenges, necessitating comprehensive and sustained efforts from international organizations, civil society, and the private sector. Economic instability, recession, and insufficient job creation significantly hinder efforts to eliminate poverty. Achieving sustained economic growth that is both inclusive and equitable is crucial for this endeavor. To address inequality, it is essential to implement policies that ensure the fair distribution of resources and opportunities. Additionally, a critical challenge is the lack of access to quality education and vocational training, which reduces the chances of securing well-paying jobs. Therefore, substantial investment in education and skills development is imperative to empower individuals and lift them out of poverty. By prioritizing these areas, we can create a more inclusive and prosperous society for all (Wietzke, 2020; Leal Filho et al., 2021).

Additionally, poor health and lack of access to affordable healthcare significantly hinder efforts to reduce poverty. Health crises, such as the COVID-19 pandemic, have further exposed vulnerabilities in healthcare systems, disproportionately affecting the poor and exacerbating existing inequalities. To mitigate these impacts, effective social protection systems are essential. These systems must provide support during times of unemployment, illness, or other crises to prevent individuals from falling deeper into poverty. Many poor individuals depend on agriculture for their livelihoods, making them particularly vulnerable to challenges such as climate change, land degradation, and market access issues. These factors can threaten food security and reduce incomes, making it even more difficult for people to escape poverty. Addressing these challenges requires comprehensive strategies that include investing in resilient agricultural practices, improving market access, and ensuring sustainable land management (Pérez-Peña et al., 2021; Lakner et al., 2022).

Limited access to credit and financial services hampers the ability of individuals and businesses in poor communities to invest, grow, and improve their economic situation. Without financial resources, it is challenging for them to start or expand businesses, invest in education, or improve their living conditions, which perpetuates the cycle of poverty. Additionally, inadequate or poor basic infrastructure, such as roads, electricity, and sanitation, has a profound impact on health, education, and economic opportunities. Poor infrastructure can lead to higher disease rates due to inadequate sanitation and lack of clean water. It can also limit educational opportunities when schools lack basic facilities or children are unable to travel safely to attend school. Furthermore, without reliable electricity, businesses cannot operate efficiently, and economic activities are severely constrained (Mhlanga, 2021; Wiratama et al., 2023).

Climate change is one of the main obstacles to poverty elimination, as extreme weather events disproportionately affect the poorest and most vulnerable communities. These events can lead to loss of livelihoods, displacement, and increased food insecurity, directly and indirectly exacerbating poverty. Corruption, political instability, and lack of accountability further undermine efforts to eliminate poverty. When resources intended for development are mismanaged or siphoned off, the effectiveness of poverty reduction programs is significantly diminished. Additionally, political instability can disrupt economic activities and deter investment, making it difficult to sustain

progress in poverty alleviation. While globalization can offer opportunities for economic development, it can also have adverse effects on vulnerable populations if not managed inclusively. Trade and investment policies must be designed to ensure they benefit all segments of society, particularly the poor. This includes creating fair trade practices, protecting workers' rights, and ensuring that investments contribute to local development. Effective governance and strong political commitment are essential for implementing successful poverty elimination policies. Governments must be transparent, accountable, and responsive to the needs of their citizens. This involves not only enacting sound policies but also ensuring their effective implementation and monitoring. Political will at all levels is crucial to prioritize poverty reduction and mobilize the necessary resources and support to achieve it (Leichenko and Silva, 2014; Obirikorang et al., 2021; Birkmann et al., 2022).

4 Methodology

This paper is based on a review of grey literature and scientific publications obtained from Scopus, Google Scholar, and other online databases. For example, a search was conducted on Scopus in February 2024 using the following search criteria: TITLE (Industry 4.0) OR (fourth industrial revolution) AND (sustainability) OR (sustainable development). The obtained data shows that the number of publications and citations on the impact of Industry 4.0 technologies on sustainability or sustainable development has increased significantly over the last few years (Figure 3). Before 2017, no publication was found on this topic, while 115 publications were indexed in Scopus in 2023, showing the increasing research interest in the connection between Industry 4.0 and sustainability.

The inclusion criteria for selecting studies in the review were relevance to Industry 4.0 technologies, direct or indirect impact on poverty reduction, empirical data or case studies, and publications in English. We excluded studies that were not peer-reviewed, focused on unrelated topics, or were published before 2010. Our review process involved three stages. First, during the initial screening, we reviewed titles and abstracts to filter out irrelevant studies. Next, in the full-text review stage, we assessed the remaining studies in detail to ensure they met our inclusion criteria. Finally, in the data extraction stage, we extracted key information from each selected study, including objectives, methodologies, findings, and conclusions.

Building on the literature reviewed and the potential applications of Industry 4.0 to address socioeconomic challenges, particularly the elimination of poverty in Africa, we propose a comprehensive framework. This framework considers an in-depth exploration of the core technologies that define Industry 4.0, including AI, IoT, blockchain, and big data, and their potential impact on socioeconomic development. We analyzed the requirements for poverty elimination, highlighted the pivotal role of these technologies, and identified critical gaps where Industry 4.0 could provide substantial benefits. Furthermore, the framework takes into account the prerequisites for implementing Industry 4.0 technologies in the context of African countries, emphasizing outcomes, challenges, and best practices. This qualitative approach aims to develop a conceptual framework that guides the effective application of Industry 4.0 technologies in poverty elimination efforts.
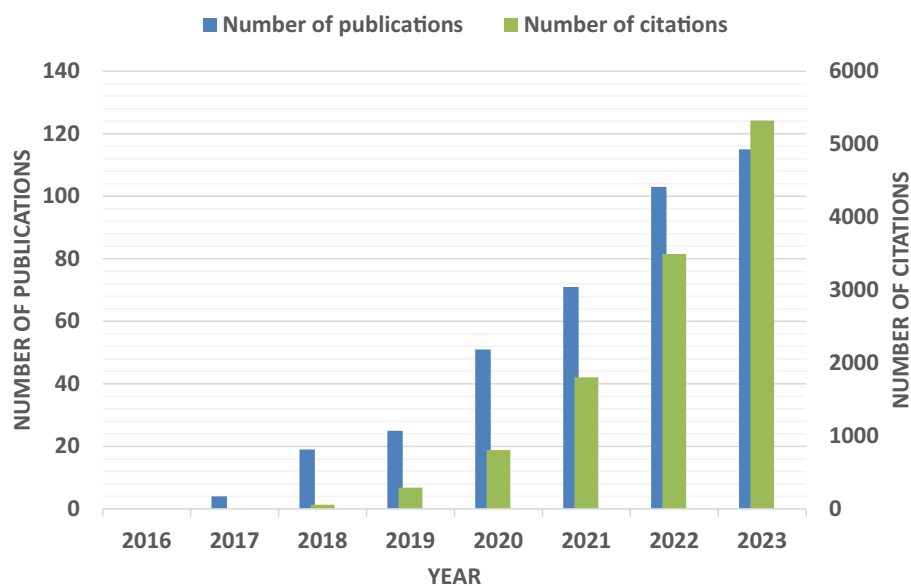
FIGURE 3
Evolution of publications and citations' number on the use of Industry 4.0 sustainability.

5 Application and analysis

5.1 Industry 4.0 for poverty elimination

Industry 4.0 can contribute to addressing the root causes of poverty by transforming economic activities, creating new job opportunities in innovative technological sectors, and improving access to essential services. Here are several ways in which Industry 4.0 can contribute to poverty elimination:

5.1.1 Sustainable agriculture

Leveraging various Industry 4.0 technologies can significantly increase agricultural productivity by optimizing resource use (such as water, fertilizers, and pesticides) and increasing crop yields, which help solve problems such as small profit margins, malnutrition, etc. This is particularly beneficial for smallholder farmers in developing countries, potentially lifting them out of poverty. Once digital solutions are affordable, they can streamline agricultural supply chains, reducing post-harvest losses and ensuring that farmers get a fair price for their produce (Nedumaran et al., 2020; Arora et al., 2022; Kazancoglu et al., 2023). By optimizing farming practices based on real-time data, farmers can significantly boost crop yields, thereby improving their income and livelihoods. Precision agriculture enables efficient use of water, fertilizers, and pesticides, reducing both costs and environmental impact (Trivelli et al., 2019; García et al., 2020). This approach is especially crucial for smallholder farmers with limited resources, ensuring sustainable agricultural practices and enhanced economic resilience. By leveraging Industry 4.0 technologies, sustainable agriculture can become a reality, significantly enhancing productivity, profitability, and food security for smallholder farmers in developing countries. This not only helps lift them out of poverty but also contributes to overall economic development and resilience against climate change.

5.1.2 Digital platforms

Industry 4.0 technologies hold tremendous potential for improving healthcare access, enhancing education and skill development, and facilitating access to financial services. Digital learning platforms can make quality education more accessible to people in remote or underserved areas, providing them with the skills needed to participate in the new economy (Abdul Bujang et al., 2020). Telemedicine and digital health services can improve access to healthcare for impoverished communities, reducing the disease burden and allowing individuals to lead healthier, more productive lives (Ibrahim et al., 2021). Through the availability and ease of accessibility to mobile banking and digital payment systems, financial services can be provided to those previously excluded from the formal banking sector, enabling savings, access to credit, and secure transactions (Kshetri, 2017a). By enhancing healthcare access through telemedicine, facilitating education and skill development via e-learning platforms and virtual classrooms, and providing greater access to financial services through mobile banking and fintech innovations, these technologies can significantly contribute to socio-economic development and poverty reduction.

5.1.3 Efficient production and operations management

Industry 4.0 technologies streamline production processes and minimize waste, significantly boosting output and curbing costs. This fosters economic growth and has the potential to reduce consumer prices, directly benefiting low-income populations. By creating new job opportunities in emerging sectors, these technologies can play a crucial role in reducing poverty. Enhancing the resilience of supply chains and increasing productivity and efficiency across various sectors ensure reliable goods delivery to remote or underserved communities, further supporting poverty alleviation. By fostering economic diversification, these technologies reduce dependency on traditional industries and create more resilient economies, ultimately

contributing to sustainable poverty reduction (Müller et al., 2018; Guo et al., 2021).

5.1.4 Infrastructure development and inclusive innovation

Industry 4.0 technologies can be pivotal in developing smarter, more efficient infrastructure systems for transportation, energy, and water management. These advancements directly benefit low-income populations by reducing costs and improving quality of life, while also supporting sustainable economic growth for the entire population. Innovations in renewable energy technologies, for example, can provide affordable and clean energy to impoverished areas, enhancing energy security and fostering economic development (Aheleroff et al., 2022; Javaid et al., 2022b). Promoting inclusive innovation ensures that the benefits of Industry 4.0 are accessible to all, including marginalized and underserved populations. Policies and programs that support inclusive innovation can help bridge the digital divide and ensure that technological advancements contribute to reducing inequality (Phiri et al., 2016). By leveraging these technologies and promoting inclusive policies, we can create resilient infrastructure that not only addresses the immediate needs of the poor but also promotes long-term, inclusive growth.

5.2 Example of application of industry 4.0 technologies in eliminating poverty

Industry 4.0 technologies have been implemented in various projects across the globe with the objective of combating poverty. These projects leverage advancements, such as AI, robotics, IoT, big data analytics, and blockchain to create innovative solutions to poverty-related challenges. By integrating these technologies, these initiatives aim to enhance productivity, improve access to essential services, and create sustainable economic opportunities for disadvantaged communities.

5.2.1 Harnessing the potential of Artificial Intelligence (AI) in poverty alleviation

In several developing countries, projects have harnessed the power of AI to enhance agricultural productivity among smallholder farmers, who are among the most vulnerable to poverty. Mhlanga (2021) explored the transformative impact of AI within the context of Industry 4.0, particularly on poverty reduction in emerging economies. Industry 4.0 enhances data availability, computational capabilities, and algorithmic efficiency, enabling AI to contribute significantly to poverty alleviation. For instance, AI improves automation and decision-making in agriculture, leading to higher productivity and better resource management. Mhlanga argued that AI's benefits extend beyond agriculture, enhancing education (SDG 4) and industry, innovation, and infrastructure (SDG 9), accelerating the attainment of SDG 1 (no poverty). By optimizing farming practices and boosting productivity, AI-driven initiatives can significantly improve the livelihoods of smallholder farmers and contribute to broader economic development, thus offering a holistic approach to tackling poverty in developing countries. For example, in a recent study, the potential of smart agriculture to alleviate poverty was examined by exploring how AI and other Industry 4.0

technologies can enhance productivity, sustainability, and profitability for smallholder farmers in low-income areas (Abrar-Ul-Haq et al., 2024). The results demonstrated the potential of these technologies in improving resource utilization, crop yields, and incomes while enhancing market access and information sharing.

Another application area of AI is in poverty prediction, leading to more accurate and comprehensive poverty assessments. AI models can utilize both field data and remote sensing data to predict poverty outcomes through various innovative approaches. For instance, the combination of satellite imagery and machine learning techniques can effectively measure living environment deprivation and identify poverty-stricken areas (Usmanova et al., 2022; Hall et al., 2023). These predictive models enable targeted interventions and resource allocation, improving the efficiency and effectiveness of poverty alleviation efforts. In another study, Abrar-Ul-Haq et al. (2024) explored how smart manufacturing, integrating advanced technologies, including AI, among others, can align with the SDGs to reduce poverty. The authors showed that by creating employment opportunities, enhancing income levels, and improving living conditions in low-income communities, smart manufacturing has the potential to transform traditional industries and promote inclusive economic development. The research highlighted the importance of technological innovation for achieving sustainable economic growth, offering policy recommendations to ensure equitable distribution of these benefits.

AI has also been extensively applied in the context of energy poverty, offering innovative solutions to complex challenges (López-Vargas et al., 2022; Ananya Hadadi Raghavendra et al., 2023). For example, a study conducted in Spain used AI to analyze energy poverty in warm climate zones, which are highly vulnerable to climate change (Bienvenido-Huertas et al., 2023). This study utilized simulated energy consumption data, energy prices, and family income data to train and test prediction models using algorithms, such as multilayer perceptron and random forest. The results demonstrated that AI models could accurately identify households experiencing energy poverty with high precision, providing valuable decision support for energy managers and social workers to optimize resource allocation and intervention strategies.

5.2.2 Harnessing the potential of robots in poverty alleviation

Robotics can offer significant opportunities to mitigate various issues related to SDGs, particularly the elimination of poverty (SDG 1). Robotic technology-driven solutions can be leveraged to reduce poverty by improving productivity, lowering the cost of goods, and freeing up personal time (Haidegger et al., 2023). When combined with other Industry 4.0 technologies such as AI, robotics can significantly enhance agricultural productivity through better utilization of resources, such as water and land, thereby contributing to poverty alleviation (Goralski and Tan, 2022). Robots can automate labor-intensive tasks in agriculture, enabling precise planting, monitoring, and harvesting of crops, which increases efficiency and yields. This not only boosts food production but also reduces labor costs, making essential goods more affordable for low-income communities. Furthermore, robots can facilitate access to education and healthcare in remote areas by providing services that were previously unavailable, such as remote learning platforms and telemedicine.

5.2.3 Application of blockchain in poverty alleviation

Implementing blockchain in the supply-and-distribution chain can bring major economic gains. For example, in agriculture, blockchain-based systems can be used to enhance traceability, ensuring that every step of the supply chain is transparent and verifiable. This improves consumer confidence in the authenticity and safety of food products. Additionally, blockchain facilitates seamless information sharing among stakeholders, reducing agricultural transaction costs and increasing overall efficiency. By providing a secure and immutable record of transactions, blockchain technology helps streamline operations, reduce fraud, and ensure fair pricing for farmers, contributing to a more sustainable and trustworthy agricultural sector (Feng et al., 2020).

In the financial sector, blockchain can significantly enhance transparency, trust, and reputation while increasing transaction efficiency. This technology reduces financial exclusion in Global South countries by providing secure and accessible financial services, thereby contributing to poverty reduction. Blockchain's decentralized nature ensures that all transactions are transparent and immutable, which builds trust among users and reduces the risk of fraud. By streamlining financial processes and reducing intermediary costs, blockchain makes financial services more affordable and accessible to underserved populations, fostering economic inclusion and growth (Kshetri, 2017a; Trendov et al., 2019).

Blockchain technology is frequently utilized in precision poverty alleviation within the agriculture sector to enhance efficiency and economic benefits. By leveraging blockchain, agricultural operations can save significant manpower and material resources. This technology provides precise tracking and transparent records of transactions and supply chains, leading to optimized resource allocation and reduced wastage (Xu et al., 2022). Consequently, the implementation of blockchain results in substantial improvements in overall efficiency and economic gains across the agricultural field, facilitating more effective and targeted poverty alleviation efforts. Combining blockchain with other Industry 4.0 technologies, such as IoT, can create a decentralized targeted poverty alleviation system that enhances openness and transparency of information, ensures safe and reliable data, and provides convenient services (Zhang, 2022; Aliyu et al., 2023).

5.2.4 Application of the Internet of Things (IoT) in poverty alleviation

IoT is increasingly being utilized in the Global South across various fields to address some of the fundamental causes of poverty (Kshetri, 2017b). IoT can play significant roles in promotion of agricultural activities, food security, and poverty alleviation. IoT devices such as soil moisture sensors, weather stations, and GPS-equipped machinery are being used to monitor and optimize agricultural activities. These technologies help farmers make data-driven decisions, reduce water usage, and increase crop yields, which directly impact food security and income levels in rural areas in developing countries (Antony et al., 2020; Padilla-Medina et al., 2022). For example, in countries like Kenya and India, the deployment of mobile platforms and IoT devices has revolutionized smallholder farming through precision agriculture services and digital livestock tools. These technologies provide farmers with SMS-based advice on optimal farming practices, real-time weather forecasts, and current market prices. The adoption of such advanced tools has significantly increased agricultural productivity and farmers' incomes, contributing to substantial poverty alleviation in rural areas.

By empowering farmers with timely and accurate information, these technologies help optimize resource use, reduce crop losses, and improve market access, ultimately fostering economic growth and improving livelihoods (Daum et al., 2022; Tripathi et al., 2022).

Another application of IoT for poverty alleviation is in smart energy management. IoT devices optimize energy usage in homes and businesses, reducing costs and increasing access to reliable power. Smart meters and IoT-enabled energy management systems monitor consumption patterns and provide real-time feedback to users, helping them manage and reduce their energy bills. This is particularly beneficial in low-income areas where energy costs can be a significant burden. For example, in Korea, an IoT-based system was developed to monitor indoor thermal environments and occupancy in energy poverty households (Yun et al., 2024). This system used various sensors to measure temperature, humidity, CO_2 levels, and occupancy, providing real-time data to optimize energy usage. Implementing this system significantly improved heating and cooling management, leading to better energy efficiency and reduced energy costs.

5.2.5 Use of big data in poverty alleviation

Another Industry 4.0 technology that can be effective in poverty alleviation is big data. Big data analytics can be leveraged to identify patterns and trends in various sectors, such as agriculture, healthcare, and finance, which can inform policy decisions and targeted interventions aimed at reducing poverty (Njuguna and McSharry, 2017; Hassani et al., 2019; Hall et al., 2023). Big data helps in precision farming by analyzing soil health, weather patterns, and crop yields, enabling farmers to make data-driven decisions that enhance productivity and reduce costs (Iaksch et al., 2021; Alahmad et al., 2023). In healthcare, big data analytics predicts disease outbreaks, tracks patient health trends, and optimizes resource allocation, leading to better health outcomes and reduced healthcare costs (Karatas et al., 2022). Big data improves financial inclusion by analyzing transaction patterns to assess creditworthiness, enabling access to microloans and financial services for underserved populations (Mhlanga, 2024).

Liang and Wang (2022) utilized multisource big data fusion and a statistical analysis model to explore precision poverty alleviation. Their research focused on analyzing the background, development status, and outcomes of poverty alleviation efforts, using typical cases to identify challenges and improvement paths. By comparing the accuracy of three models, the study found that the random forest model had the lowest error rate, achieving a 90.26% accuracy rate in identifying poor households. This empirical analysis provided valuable insights into the contribution rate of various indicators leading to multidimensional poverty, establishing scientific criteria for accurately identifying poor farm households and enhancing poverty alleviation strategies. In a similar study, a clustering algorithm was proposed to accurately identify poverty characteristics in poor households using big data, uncovering the true causes of poverty and facilitating better assistance measures (Liu et al., 2021). The developed model shows good performance, achieving an accuracy rate of more than 96%. Moreover, coupling big data with AI can significantly reduce energy poverty by analyzing socioeconomic and environmental factors (Hassani et al., 2019).

5.2.6 Use of 5G in poverty alleviation

The 5G technology is considered a fundamental requirement in the current digital era due to its potential to significantly improve network efficiency and capacity. It enables faster data transmission, reduced

latency, and increased connectivity, which can enhance various sectors, such as healthcare, education, and finance. By facilitating better access to information and services, 5G can create substantial social value and contribute to global poverty reduction. Improved connectivity can support economic development, increase employment opportunities, and provide essential services to underserved communities, thereby promoting inclusive growth. In agriculture, this technology can help enhance productivity and decrease production cost through providing farmers in rural areas with a wide range of useful data, such as real-time weather information and product prices (Cabanillas-Carbonell et al., 2023). For example, the "Hello Tractor" initiative in Nigeria and Kenya is a service that uses an app to connect smallholder farmers needing tractor services. This innovative service optimizes the use of machinery, improving agricultural productivity and reducing costs for farmers (Lopez-Vargas et al., 2020). By leveraging 5G technology, the app enhances connectivity and real-time communication, ensuring efficient matching and scheduling. This initiative not only increases crop yields but also contributes to poverty reduction by enabling smallholders to access affordable mechanization, thereby enhancing their economic opportunities and livelihoods.

5.3 What is required for Africa and developing countries to adopt Industry 4.0?

Applying Industry 4.0 to the challenges in Africa and developing countries involves addressing several key factors, including infrastructure development, education and skills development, finance and capital for investment, regulatory and policy framework, and collaborations and partnerships, among others (Jellason et al., 2021).

5.3.1 Infrastructure development

For Africa and other developing countries to harness Industry 4.0 technologies effectively, they need reliable and widespread internet access. Currently, both the price and quality of internet connections in Africa lag behind other regions. Expanding broadband coverage and ensuring affordable internet services are crucial for facilitating the adoption of digital technologies. Additionally, stable and reliable electricity, potentially provided by renewable energy sources, is essential for powering Industry 4.0 infrastructure (Trendov et al., 2019; Ukoba et al., 2023).

5.3.2 Education and skill development

Africa requires a solid educational foundation at all levels to develop a future-ready workforce. This includes focused programs that provide practical skills in areas such as AI, robotics, and data analytics, essential for preparing individuals for Industry 4.0 jobs. Furthermore, there must be a culture that encourages continuous learning and offers opportunities for reskilling to help the current workforce adapt to new technologies (Moshtari and Safarpour, 2023).

5.3.3 Regulatory and policy framework

Governments should implement policies that foster innovation, support startups, and facilitate the growth of the digital economy. Establishing robust legal frameworks for data protection and cybersecurity will build trust in digital services and safeguard against cyber threats. Public–private partnerships and collaborations with academic institutions can enhance research and development capabilities, driving innovation (Raj et al., 2020; Mhlanga and Ndhlovu, 2023).

5.3.4 Investment and funding

Research should focus on developing solutions tailored to local challenges, such as agricultural technology, health tech, and sustainable energy solutions. Providing startups and SMEs with access to capital through venture funding, grants, and loans is crucial for developing new technologies and business models. Supporting entrepreneurship through incubators and accelerators and investing in enhancing innovation can help nurture innovative ideas and bring them to market (Shkabatur et al., 2022).

5.3.5 Collaborations, partnerships, and sustainability and inclusivity

Supporting partnerships with international organizations and developed countries can facilitate knowledge and technology transfer. International development programs can significantly build capacity, offer technical assistance, and share best practices. Industry 4.0 initiatives should align with SDGs, ensuring environmental protection and long-term economic viability. Efforts must be made to ensure that advancements benefit all sectors of society, including marginalized groups, to promote inclusive growth and sustainable development (Nair and Landani, 2020; UNIDO, 2020; World Economic Forum, 2020; Zougmoré et al., 2021).
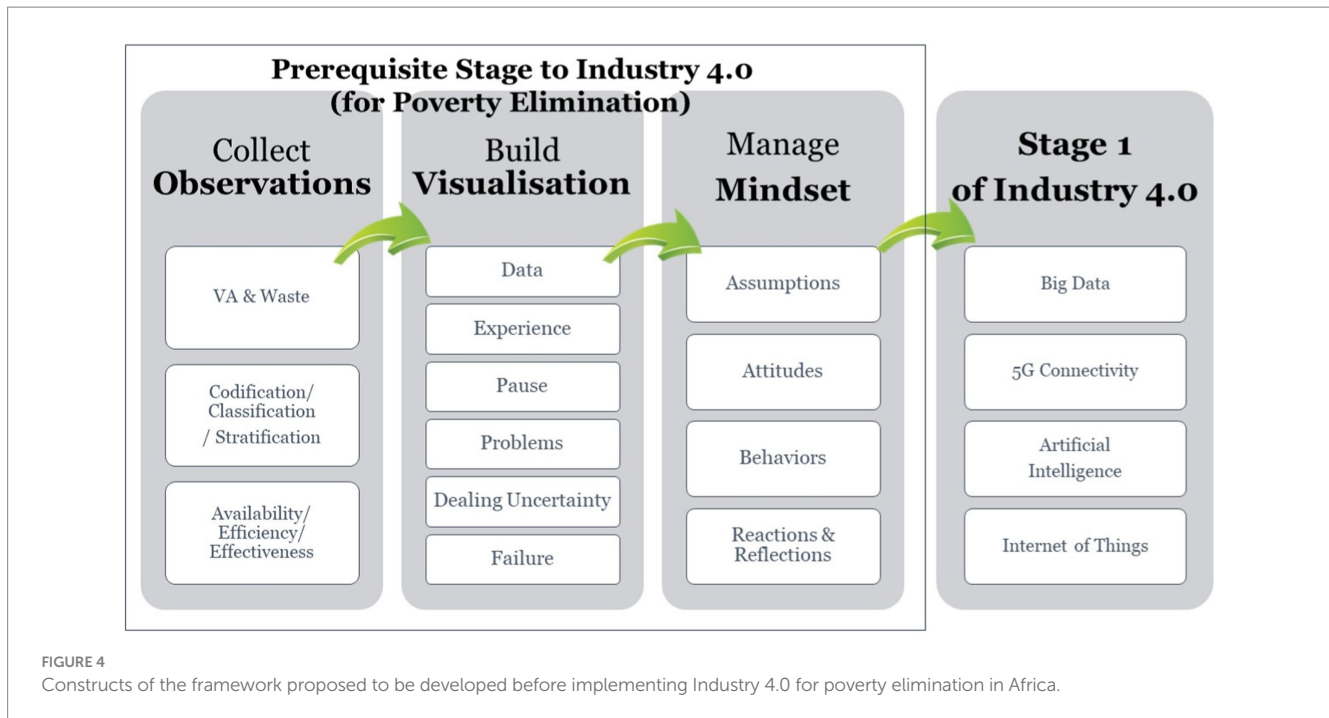
6 Framework proposed for applying Industry 4.0 for poverty elimination in Africa

Implementing Industry 4.0 technologies for poverty elimination in Africa requires laying a solid groundwork. The proposed framework includes four main constructs: observation, visualization, mindset management, and the initial stage of Industry 4.0 implementation (Figure 4). These constructs are crucial for creating opportunities, driving economic growth, and fostering innovation.

6.1 Importance of the observation construct

Effective observation is critical to understanding community needs, living conditions, and available resources. This involves assessing infrastructure, health facilities, educational institutions, and economic activities. Observations should focus on identifying value-added (VA) opportunities and waste within communities. By visiting households and engaging directly with community members, observers can gain insights into the daily challenges faced by families in poverty, allowing for tailored interventions. Observations should also include codification, classification, and stratification of collected data to better understand and address specific needs.

Furthermore, observations enhance the availability, efficiency, and effectiveness of poverty elimination efforts by ensuring that interventions are based on accurate and comprehensive data. Regular observation helps monitor progress, ensuring interventions are carried out as planned and identifying any deviations or challenges early on. This continuous

FIGURE 4
Constructs of the framework proposed to be developed before implementing Industry 4.0 for poverty elimination in Africa.

monitoring allows for adaptive management, where interventions can be modified in response to observed changes in the community or environment. Observing local practices and resources can reveal innovative solutions that may be strengthened or replicated, building trust and fostering community ownership. Post-intervention observations assess the changes in the community or households, evaluating the direct and indirect impacts of the poverty elimination efforts.

In summary, observation provides a rich, qualitative understanding that complements quantitative data, offering a holistic view of the challenges and opportunities in tackling poverty. It requires careful planning, cultural sensitivity, and ethical consideration to ensure it contributes effectively to project goals.

6.2 Importance of the visualization construct

Visualization, based on data analysis, the experience, taking a pause, dealing with problems, dealing with uncertainty and learning from failures, enhances understanding and communication of complex data. Tools such as geographic information systems can map poverty, identify hotspots, and overlay various datasets to reveal underlying factors. Visualizations like line graphs and dashboards track poverty rates and intervention impacts over time, aiding policymakers in choosing effective strategies.

Real-time data visualization dashboards monitor progress using metrics like access to education, healthcare, employment rates, and living standards improvements. Effective visualizations should incorporate storytelling, infographics, and interactive tools to communicate challenges and successes, engaging a broader audience, including the public, donors, and policymakers. These tools facilitate data sharing, promote cooperation, and make complex data understandable and actionable, empowering stakeholders to make informed decisions and track progress in poverty eradication efforts.

6.3 Importance of the mindset management construct

The framework emphasizes the crucial role of managing mindsets and assumptions about poverty and its complexities. This involves addressing and shaping attitudes, behaviors, reactions, and reflections related to poverty. The importance of mindset in poverty elimination projects cannot be overstated. Shifting mindsets is vital for the success of poverty elimination initiatives. Encouraging resilience, self-efficacy, and a collective belief in improvement fosters community engagement and participation. It is essential to cultivate a mindset open to long-term goals, continuous learning, and adaptation to changing circumstances. This adaptability ensures that communities are prepared to handle setbacks and evolving challenges effectively. Overcoming stereotypes and biases through critical thinking and empathy is crucial. Negative stereotypes and biases can hinder the effectiveness of poverty elimination efforts by perpetuating misconceptions and reducing the willingness to engage in meaningful change. Encouraging critical thinking helps individuals challenge these stereotypes, fostering a more inclusive and supportive environment for poverty alleviation efforts.

Educational curricula and workshops play a significant role in mindset management. By integrating mindset-oriented programs that emphasize self-efficacy, critical thinking, and resilience, communities can be better equipped to face challenges. Success stories within and across communities are powerful tools to inspire belief in the possibility of change and improvement. These narratives provide tangible examples of progress, motivating individuals and communities to take proactive steps toward poverty elimination. Additionally, mentorship programs and support networks are essential for reinforcing positive mindsets. These initiatives provide practical assistance, encouragement, and advice, helping individuals navigate the complexities of poverty

elimination efforts. By fostering a supportive community, these programs can enhance the collective effort towards sustainable development.

In summary, managing mindsets is a foundational element of the framework, essential for creating a conducive environment for poverty elimination. By promoting resilience, self-efficacy, and critical thinking, and by addressing stereotypes and biases, stakeholders can cultivate a collective belief in improvement and sustainable development.

6.4 Implementation of the first stage of Industry 4.0

Industry 4.0 is the next revolution that will include new digital innovations and improve several existing technologies in developing countries. The core principle of Industry 4.0 is based on the convergence between digital, physical, and biological scientific domains, which allow make significant progress and overcome complex challenges, including poverty eradication. Although growing evidence from many manufacturing fields in developed countries shows that Industry 5.0 (referring to the fifth industrial revolution) is already underway (Ghobakhloo et al., 2022; Maddikunta et al., 2022; Baig and Yadegaridehkordi, 2023), Africa has just started to grasp the aspects of Industry 4.0.

Implementing the first stage of Industry 4.0 requires affordable high-speed internet connectivity and upgrading existing infrastructure. Indeed, IT infrastructure and network in rural areas are among the basic conditions for implementing the first stage of Industry 4.0 in Africa. With the growing utilization of smartphones and other digital devices in Africa, farmers and other agriculture businesses may be able in the coming few years to transmute into digital agriculture ushering in a new era of economic growth in developing countries. Africa, which has been left behind during the past industrial revolutions can hope to unlock the potential of ongoing Industry 4.0, bridging the development gap with the rest of the world.

6.5 Strategies to reduce bias in the framework

Several strategies can be incorporated into the proposed framework to reduce the risk of bias in observations and other processes.

Firstly, developing standardized protocols for data collection will ensure consistency and minimize subjective interpretation. Training observers in cultural sensitivity and bias recognition will further reduce personal biases. Using triangulation, which involves multiple data sources and methods, will validate findings and enhance reliability. Conducting blind observations, where observers are unaware of expected outcomes, will also prevent bias. Engaging community members in the observation process will provide diverse perspectives and ensure that local knowledge is accurately represented. Ensuring data transparency by documenting and sharing methodologies will build trust and credibility. Inclusive representation through participatory mapping and involving the community in visualization processes will help depict accurate and comprehensive data.

Raising awareness about cognitive biases through workshops and encouraging critical reflection among project teams will help manage

mindsets. Establishing feedback mechanisms for community input will ensure that diverse viewpoints are considered and incorporated. During the implementation of Industry 4.0 technologies, conducting pilot tests will help identify and mitigate biases before broader application. Independent audits and real-time data analytics will provide objective evaluations and reduce human bias in decision-making processes. These integrated strategies will ensure that observations and subsequent actions are unbiased, reliable, and effective in leveraging Industry 4.0 technologies for poverty elimination.

7 Implications and limitations of the study

This study highlights the essential need for establishing a robust foundational framework, as outlined in the conceptual framework, before deploying Industry 4.0 technologies in poverty alleviation projects. The proposed framework serves as a strategic guide for policymakers, technologists, and development practitioners to effectively harness advanced technologies for socioeconomic development, with a particular focus on poverty reduction in Africa. The study identified key areas where Industry 4.0 can make a significant impact on poverty, including sustainable agriculture through precision farming and smart agriculture techniques, digital platforms that enable access to information, education, and economic opportunities, efficient production and operations management via automation and advanced manufacturing processes, and infrastructure development alongside inclusive innovation that incorporates marginalized communities. The primary Industry 4.0 technologies that can be leveraged in these contexts include AI for predictive analytics and decision-making support, robotics to automate repetitive tasks and improve efficiency, blockchain for ensuring transparency and security in transactions, IoT for real-time data collection and monitoring, big data to analyze vast amounts of information for insights and trends, and 5G to provide the necessary connectivity for seamless technology integration.

While this study lays a foundational understanding of how Industry 4.0 technologies can be utilized for poverty elimination, further research is essential to explore specific implementation strategies and their varied outcomes in different contexts. Future studies should delve into the detailed roles of each Industry 4.0 technology in poverty alleviation, offering a comprehensive analysis. Additionally, empirical research is necessary to test the applicability and effectiveness of the proposed framework in real-world settings across various African countries. This paper also paves the way for new research avenues, investigating the socioeconomic impacts of specific Industry 4.0 interventions in poverty-stricken areas, with a focus on continuous improvement. The documentation of case studies highlighting successes, challenges, and lessons learned would be invaluable. Furthermore, exploring the role of cross-sector partnerships in scaling up the deployment of Industry 4.0 technologies for social good is recommended, emphasizing collaborative models between governments, the private sector, academia, and civil society to address complex socioeconomic challenges effectively.

Due to the limited scope of this paper, which serves as an introduction to a new line of work, the authors did not conduct semi-structured or structured interviews with key stakeholders, including academics, industry professionals, policymakers, and representatives from non-governmental organizations. Future research should

undertake such interviews to gather deeper insights into the practical application of Industry 4.0 technologies, identify potential barriers, and devise strategies for successful implementation. By incorporating feedback from these interviews, the proposed framework can be further detailed with additional key components essential for integrating Industry 4.0 technologies into poverty elimination strategies, particularly in the African context. This comprehensive framework will encompass technological, social, economic, and policy dimensions. It is recommended that the collected data be analyzed using thematic analysis to identify common themes, insights, and recommendations. These findings will then be integrated with insights from the literature review to refine and validate the proposed framework, ensuring it is robust and effective in addressing the multifaceted challenges of poverty.

8 Future directions and conclusions

This study underscores the transformative potential of Industry 4.0 technologies in addressing poverty. Through an extensive literature review, critical areas were identified where technologies such as AI, IoT, big data, blockchain, 5G, and robotics can significantly impact socioeconomic development and poverty reduction. The proposed conceptual framework emphasizes the need for strategic policy interventions, capacity building, and infrastructural development to ensure these technologies benefit the most vulnerable populations and prevent deepening the digital divide. The findings suggest that effectively leveraging Industry 4.0 technologies for poverty elimination requires a coordinated approach involving multiple stakeholders and multidisciplinary collaboration. Governments, private sector players, non-governmental organizations, and international organizations should work together to create enabling environments that foster technological innovation while ensuring inclusivity and accessibility. Investments in digital infrastructure, education, and skills training are paramount to preparing the workforce for the new economy and ensuring equitable distribution of the benefits of these technological advancements (Crespo Cuaresma et al., 2018; Leal Filho et al., 2021; Barbier and Edward Barbier, 2023).

Industry 4.0 offers unprecedented opportunities to accelerate progress towards eradicating poverty by harnessing technological advancements. By adopting a holistic approach, as outlined in the proposed framework, Industry 4.0 can become a pivotal element in the fight against poverty, transforming lives and communities for the better. Industry 4.0 can address multidimensional poverty in Africa through a multidisciplinary approach that combines economic development with social policies to improve health, education, and living standards. Technologies can provide information, education, healthcare, and better economic opportunities, enabling poor people to overcome poverty. Additionally, enhancing agricultural productivity, diversifying economies, and improving access to global markets can provide a more stable foundation for reducing poverty (Leichenko and Silva, 2014; Shkabatur et al., 2022; Stefanidis et al., 2024). Realizing the potential of Industry 4.0 necessitates targeted efforts to ensure that technological advancements benefit all society segments, particularly the most vulnerable. Investments in infrastructure, governance reforms, gender equality, and environmental sustainability are priorities to meet new industry

standards. Governments should implement policies that foster innovation, support startups, and facilitate the growth of the digital economy. Establishing robust legal frameworks for data protection and cybersecurity will build trust in digital services and safeguard against cyber threats. Public–private partnerships and collaborations with academic institutions can enhance research and development capabilities, driving innovation.

Before embarking on advanced projects based on Industry 4.0 principles, the importance of observations, visualization, and mindset management cannot be overstated. Observation is crucial in understanding the realities of communities affected by poverty, assessing intervention effectiveness, and identifying needs and opportunities for sustainable development. Visualization helps stakeholders understand complex data, identify patterns, monitor progress, and communicate findings effectively. Enhancing the mindset's capacity is foundational in the fight against poverty. Projects that cultivate empowering mindsets and overcome silo mentality are more likely to achieve meaningful, sustainable outcomes. By addressing both the material and psychological aspects of poverty, Industry 4.0 technologies can foster circular economy and resilience, encourage innovation, and mobilize communities toward their own development (Chari et al., 2022; Javaid et al., 2022a; Mhlanga, 2022).

The goal of eradicating poverty should be achieved together with strategies for improving health and education, eliminating inequalities and violence, stimulating economic growth, mitigating climate change, and preserving ecosystems. Global initiatives to eradicate poverty are encapsulated in SDGs, unanimously adopted by all United Nations Member States in 2015. SDG 1 aims to end poverty in all its forms everywhere by 2030. Achieving this goal necessitates a collaborative efforts from governments, international organizations, the private sector, and civil society, focusing on tackling the root causes of poverty, promoting inclusive economic growth, and ensuring universal access to essential services.

Implementing advanced technologies and digital innovations holds significant potential for poverty elimination. Industry 4.0 can transform the economy, enhance productivity, and create new jobs. In Africa, the first application area of these technologies could be in agriculture, enabling a transition to precision/smart farming and digital agriculture. However, many other areas can benefit from Industry 4.0 technologies, helping to fight inequality and reduce poverty. To harness the benefits of digital transformation, Africa must identify and leverage emerging opportunities in agriculture and industry to drive sustainable and inclusive development.

To overcome current socioeconomic, technical, and technological obstacles, a multidisciplinary and collaborative approach is crucial. By doing so, Africa can effectively utilize Industry 4.0 technologies to foster innovation and create a resilient, prosperous future for all. This study sets the direction for future efforts to harness Industry 4.0 in the service of humanity's most pressing challenge—eliminating poverty. The impact of Industry 4.0 on socioeconomic issues is complex and multifaceted, but its potential to drive economic growth, enhance automation, digitalization, sustainability, and improve living standards is substantial.

In conclusion, Industry 4.0 offers a pathway to address poverty and promote socioeconomic development. However, realizing its full potential requires strategic investments, policy support, and a

concerted effort to ensure inclusivity and accessibility. By fostering innovation, encouraging collaboration, and prioritizing sustainability, we can leverage Industry 4.0 technologies to build a more equitable and prosperous future for all.

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RA: Funding acquisition, Project administration, Resources, Software, Writing - original draft. MB: Conceptualization, Methodology, Writing – original draft. AH: Conceptualization, Methodology, Validation, Writing – original draft, Writing – review & editing.

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References

Abbate, S., Centobelli, P., and Cerchione, R. (2023). The digital and sustainable transition of the Agri-food sector. *Technol. Forecast. Soc. Chang.* 187:122222. doi: 10.1016/j.techfore.2022.122222

Abdul Bujang, S. D., Selamat, A., Krejcar, O., Maresova, P., and Nguyen, N. T. (2020). Digital learning demand for future education 4.0—case studies at Malaysia education institutions. *Informatics* 7:13. doi: 10.3390/INFORMATICS7020013

Abrar-Ul-Haq, M., Sankar, J. P., Akram, F., Islam, G. M. N., Malik, H. A. M., and Akram, K. (2024). Aligning AI-led smart manufacturing with SDGs for poverty reduction. 2024 IEEE 1st Karachi Section Humanitarian Technology Conference, Khi-HTC 2024

Abrar-Ul-Haq, M., Sankar, J. P., Akram, F., and Malik, H. A. M. (2024). Harvesting prosperity: AI-powered solutions for household poverty reduction through smart agriculture. 2024 IEEE 1st Karachi Section Humanitarian Technology Conference, Khi-HTC 2024

Aheleroff, S., Huang, H., Xu, X., and Zhong, R. Y. (2022). Toward sustainability and resilience with industry 4.0 and industry 5.0. *Front. Manufact. Technol.* 2, 1–20. doi: 10.3389/fmtec.2022.951643

Alahmad, T., Neményi, M., and Nyéki, A. (2023). Applying IoT sensors and big data to improve precision crop production: a review. *Agronomy* 13:2603. doi: 10.3390/AGRONOMY13102603

Aliyu, A. A., Liu, J., Aliyu, A. A., and Liu, J. (2023). Blockchain-based smart farm security framework for the internet of things. *Sensors* 23:7992. doi: 10.3390/S23187992

Ananya Hadadi Raghavendra, S. G. M., Mukherjee, A., and Bala, P. K. (2023). Role of artificial intelligence (AI) in poverty alleviation: a bibliometric analysis. *VINE J. Inf. Knowledge Manag. Syst.* 5:e104. doi: 10.1108/VJIKMS-05-2023-0104

Antony, A. P., Leith, K., Jolley, C., Lu, J., and Sweeney, D. J. (2020). A review of practice and implementation of the internet of things (IoT) for smallholder agriculture. *Sustainability* 12, 1–19. doi: 10.3390/su12093750

Arora, C., Kamat, A., Shanker, S., and Barve, A. (2022). Integrating agriculture and industry 4.0 under "Agri-food 4.0" to analyze suitable technologies to overcome agronomical barriers. *Br. Food J.* 124, 2061–2095. doi: 10.1108/BFJ-08-2021-0934

Asadullah, M. N., Savoia, A., and Sen, K. (2020). Will South Asia achieve the sustainable development goals by 2030? Learning from the MDGs experience. *Soc. Indic. Res.* 152, 165–189. doi: 10.1007/s11205-020-02423-7

Atangana, E. (2022). With the continuing increase in sub-Saharan African countries, Will sustainable development of goal 1 ever be achieved by 2030? *Sustainability (Switzerland)* 14:10304. doi: 10.3390/su141610304

Bai, C., Dallasega, P., Orzes, G., and Sarkis, J. (2020). Industry 4.0 technologies assessment: a sustainability perspective. *Int. J. Prod. Econ.* 229:107776. doi: 10.1016/J.IJPE.2020.107776

Baig, M. I., and Yadegaridehkordi, E. (2023). Industry 5.0 applications for sustainability: a systematic review and future research directions. *Sustain. Dev.* 32, 662–681. doi: 10.1002/SD.2699

Barbier, E. B., and Edward Barbier, C. B. (2023). Overcoming digital poverty traps in rural Asia. *Rev. Dev. Econ.* 27, 1403–1420. doi: 10.1111/RODE.12962

Bienvenido-Huertas, D., Sánchez-García, D., Marín-García, D., and Rubio-Bellido, C. (2023). Analysing energy poverty in warm climate zones in Spain through artificial intelligence. *J. Building Eng.* 68:106116. doi: 10.1016/j.jobe.2023.106116

Birkel, H., and Müller, J. M. (2021). Potentials of industry 4.0 for supply chain management within the triple bottom line of sustainability—a systematic literature review. *J. Clean. Prod.* 289:125612. doi: 10.1016/j.jclepro.2020.125612

Birkmann, J., Liwenga, E., Pandey, R., Boyd, E., Djalante, R., Gemenne, F., et al (2022). Poverty, livelihoods and sustainable development, B. R. H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck and A. Alegríaet al, (Ed.), PClimate change 2022: Impacts, adaptation and vulnerability. Contribution of working group II to the sixth assessment report of the intergovernmental panel on climate change. 1171–1274, Cambridge University Press

Buheji, M. (2019). Reviewing implications poverty and entrepreneurship in developed and developing economies. *Am. J. Econ.* 2019, 268–271. doi: 10.5923/j.economics.20190905.06

Buheji, M. (2020a). Review of lessons learned from the Asian poverty elimination efforts. *Am. J. Econ.* 2020, 5–10. doi: 10.5923/j.economics.20201001.02

Buheji, M. (2020b). Youth between labour market and NEET-critical review on the foresighted challenges. *Int. J. Human Res. Stud.* 10:171. doi: 10.5296/ijhrs.v10i1.16171

Buheji, M. (2021). Influence of multidisciplinary thinking approaches in poverty elimination–case of Afghanistan. *Int. J. Manag.* 12, 19–31. doi: 10.34218/ijm.12.9.2021.003

Buheji, Mohamed, and Ahmed, Dunya. (2019). INTENT: shaping the future of "poverty Economy." AuthorHouse. Available at: https://books.google.com/books/about/The_Intent.html?id=IN1dyQEACAAJ

Cabanillas-Carbonell, M., Pérez-Martínez, J., and Zapata-Paulini, J. (2023). Contributions of the 5G network with respect to poverty (SDG1). *Syst. Liter. Rev. Sustainabil.* 15:11301. doi: 10.3390/SU151411301

Carcellar, N., Co, J. C. R., and Hipolito, Z. O. (2011). Addressing disaster risk reduction through community-rooted interventions in the Philippines: experience of the homeless people's federation of the Philippines. *Environ. Urban.* 23, 365–381. doi: 10.1177/0956247811415581

Chari, A., Niedenzu, D., Despeisse, M., Machado, C. G., Azevedo, J. D., Boavida-Dias, R., et al. (2022). Dynamic capabilities for circular manufacturing supply chains—exploring the role of industry 4.0 and resilience. *Bus. Strateg. Environ.* 31, 2500–2517. doi: 10.1002/BSE.3040

Chmutina, K., von Meding, J., Sandoval, V., Boyland, M., Forino, G., Cheek, W., et al. (2021). What we measure matters: the case of the missing development data in Sendai framework for disaster risk reduction monitoring. *Int. J. Disaster Risk Sci.* 12, 779–789. doi: 10.1007/s13753-021-00382-2

Cho, S., and Kim, T. (2017). Determinants of poverty status in Rwanda. *Afr. Dev. Rev.* 29, 337–349. doi: 10.1111/1467-8268.12260

Crespo Cuaresma, J., Fengler, W., Kharas, H., Bekhtiar, K., Brottrager, M., and Hofer, M. (2018). Will the sustainable development goals be fulfilled? Assessing

present and future global poverty. *Palgr. Commun.* 4, 1–8. doi: 10.1057/s41599-018-0083-y

Dash, S. P. (2022). Poverty elimination in China by 2020: bringing a transformation. *Ind. J. Publ. Administr.* 68, 572–584. doi: 10.1177/00195561221109223

Daum, T., Ravichandran, T., Kariuki, J., Chagunda, M., and Birner, R. (2022). Connected cows and cyber chickens? Stocktaking and case studies of digital livestock tools in Kenya and India. *Agric. Syst.* 196:103353. doi: 10.1016/j.agsy.2021.103353

Derakhti, A., Gonzalez, E. D. R. S., and Mardani, A. (2023). Industry 4.0 and beyond: a review of the literature on the challenges and barriers facing the Agri-food supply chain. *Sustain. For.* 15:5078. doi: 10.3390/SU15065078

Feliciano, D. (2019). A review on the contribution of crop diversification to sustainable development goal 1 "no poverty" in different world regions. *Sustain. Dev.* 27, 795–808. doi: 10.1002/SD.1923

Feng, H., Wang, X., Duan, Y., Zhang, J., and Zhang, X. (2020). Applying blockchain technology to improve Agri-food traceability: a review of development methods, benefits and challenges. *J. Clean. Prod.* 260:121031. doi: 10.1016/J.JCLEPRO.2020.121031

García, L., Parra, L., Jimenez, J. M., Lloret, J., and Lorenz, P. (2020). IoT-based smart irrigation systems: an overview on the recent trends on sensors and IoT Systems for Irrigation in precision agriculture. *Sensors* 20:1042. doi: 10.3390/S20041042

Ghobakhloo, M. (2020). Industry 4.0, digitization, and opportunities for sustainability. *J. Clean. Prod.* 252:119869. doi: 10.1016/J.JCLEPRO.2019.119869

Ghobakhloo, M., Iranmanesh, M., Mubarak, M. F., Mubarik, M., Rejeb, A., and Nilashi, M. (2022). Identifying industry 5.0 contributions to sustainable development: a strategy roadmap for delivering sustainability values. *Sustain. Prod. Consumpt.* 33, 716–737. doi: 10.1016/j.spc.2022.08.003

Gomez, E. T., Cheong, K. C., and Wong, C. Y. (2021). Regime changes, state-business ties and remaining in the middle-income trap: the case of Malaysia. *J. Contemp. Asia* 51, 782–802. doi: 10.1080/00472336.2021.1933138

Goralski, M. A., and Tan, T. K. (2022). Artificial intelligence and poverty alleviation: emerging innovations and their implications for management education and sustainable development. *Int. J. Manag. Educ.* 20:100662. doi: 10.1016/j.ijme.2022.100662

Guo, D., Li, M., Lyu, Z., Kang, K., Wu, W., Zhong, R. Y., et al. (2021). Synchroperation in industry 4.0 manufacturing. *Int. J. Prod. Econ.* 238:108171. doi: 10.1016/j.ijpe.2021.108171

Haidegger, T., Mai, V., Mörch, C. M., Boesl, D. O., Jacobs, A., Rao, R. B., et al. (2023). Robotics: enabler and inhibitor of the sustainable development goals. *Sustain. Product. Consumpt.* 43, 422–434. doi: 10.1016/J.SPC.2023.11.011

Hall, O., Dompae, F., Wahab, I., and Dzanku, F. M. (2023). A review of machine learning and satellite imagery for poverty prediction: implications for development research and applications. *J. Int. Dev.* 35, 1753–1768. doi: 10.1002/JID.3751

Hassan, M. K., Alshater, M. M., Banna, H., and Alam, M. R. (2023). A bibliometric analysis on poverty alleviation. *Int. J. Ethics Syst.* 39, 507–531. doi: 10.1108/IJOES-10-2021-0191

Hassani, H., Yeganegi, M. R., Beneki, C., Unger, S., and Moradghaffari, M. (2019). Big data and energy poverty alleviation. *Big Data Cogn. Comput.* 3:50. doi: 10.3390/BDCC3040050

Hassoun, A., Abdullah, N. A., Aït-kaddour, A., Beşir, A., Zannou, O., Önal, B., et al. (2024a). Food traceability 4.0 as part of the fourth industrial revolution: key enabling technologies. *Crit. Rev. Food Sci. Nutr.* 64, 873–889. doi: 10.1080/10408398.2022.2110033

Hassoun, A., Aït-Kaddour, A., Abu-Mahfouz, A. M., Rathod, N. B., Bader, F., Barba, F. J., et al. (2023a). The fourth industrial revolution in the food industry—part I: industry 4.0 technologies. *Crit. Rev. Food Sci. Nutr.* 63, 6547–6563. doi: 10.1080/10408398.2022.2034735

Hassoun, A., Al-Muhannadi, K., Hassan, H. F., Hamad, A., Khwaldia, K., Buheji, M., et al. (2024b). From acute food insecurity to famine: how the 2023/2024 war on Gaza has dramatically set back sustainable development goal 2 to end hunger. *Front. Sustain. Food Syst.* 8:1402150. doi: 10.3389/fsufs.2024.1402150

Hassoun, A., Anusha Siddiqui, S., Smaoui, S., Ucak, İ., Arshad, R. N., Bhat, Z. F., et al. (2024c). Emerging technological advances in improving the safety of muscle foods: framing in the context of the food revolution 4.0. *Food Rev. Intl.* 40, 37–78. doi: 10.1080/87559129.2022.2149776

Hassoun, A., Bekhit, A. E. D., Jambrak, A. R., Regenstein, J. M., Chemat, F., Morton, J. D., et al. (2024d). The fourth industrial revolution in the food industry—part II: emerging food trends. *Crit. Rev. Food Sci. Nutr.* 64, 407–437. doi: 10.1080/10408398.2022.2106472

Hassoun, A., Boukid, F., Ozogul, F., Aït-kaddour, A., Miguel, J., Lorenzo, M., et al. (2023b). Creating new opportunities for sustainable food packaging through dimensions of industry 4.0: new insights into the food waste perspective. *Trends Food Sci. Technol.* 142:104238. doi: 10.1016/j.tifs.2023.104238

Hassoun, A., Jagtap, S., Garcia-garcia, G., Trollman, H., Pateiro, M., Lorenzo, M., et al. (2023c). Food quality 4.0: from traditional approaches to digitalized automated analysis. *J. Food Eng.* 337:111216. doi: 10.1016/j.jfoodeng.2022.111216

Hassoun, A., Jagtap, S., Trollman, H., Garcia-garcia, G., Alhaj, N., Goksen, G., et al. (2023d). Food processing 4.0: current and future developments spurred by the

fourth industrial revolution. *Food Control* 145:109507. doi: 10.1016/j.foodcont.2022.109507

Hassoun, A., Prieto, M. A., Carpena, M., Bouzembrak, Y., Marvin, H. J. P., Pallar, N., et al. (2022). Exploring the role of green and industry 4.0 technologies in achieving sustainable development goals in food sectors. *Food Res. Int.* 162:112068. doi: 10.1016/j.foodres.2022.112068

He, J., Fu, C., Li, X., Ren, F., and Dong, J. (2023). What do we know about multidimensional poverty in China: its dynamics, causes, and implications for sustainability. *ISPRS Int. J. Geo Inf.* 12:78. doi: 10.3390/IJGI12020078

Iaksch, J., Fernandes, E., and Borsato, M. (2021). Digitalization and big data in smart farming—a review. *J. Manag. Anal.* 8, 333–349. doi: 10.1080/23270012.2021.1897957

Ibrahim, H., Liu, X., Zariffa, N., Morris, A. D., and Denniston, A. K. (2021). Health data poverty: an assailable barrier to equitable digital health care. *Lancet Digital Health* 3, e260–e265. doi: 10.1016/S2589-7500(20)30317-4

Javaid, M., Haleem, A., Singh, R. P., and Suman, R. (2022a). Enhancing smart farming through the applications of agriculture 4.0 technologies. *Int. J. Intelligent Netw.* 3, 150–164. doi: 10.1016/j.ijin.2022.09.004

Javaid, M., Haleem, A., Singh, R. P., Suman, R., and Gonzalez, E. S. (2022b). Understanding the adoption of industry 4.0 technologies in improving environmental sustainability. *Sustain. Operat. Comput.* 3, 203–217. doi: 10.1016/j.susoc.2022.01.008

Javaid, M., Haleem, A., Vaishya, R., Bahl, S., Suman, R., and Vaish, A. (2020). Industry 4.0 technologies and their applications in fighting COVID-19 pandemic. *Diabetes Metab. Syndr.* 14, 419–422. doi: 10.1016/j.dsx.2020.04.032

Jellason, N. P., Robinson, E. J. Z., and Ogbaga, C. C. (2021). Agriculture 4.0: is sub-Saharan Africa ready? *Appl. Sci.* 11:5750. doi: 10.3390/APP11125750

Kakpo, A., Mills, B. F., and Brunelin, S. (2022). Weather shocks and food price seasonality in sub-Saharan Africa: evidence from Niger. *Food Policy* 112, 102347–102319. doi: 10.1016/j.foodpol.2022.102347

Kamruzzaman, P. (2021). Understanding extreme poverty in the words of the poor–a Bangladesh case study. *J. Poverty* 25, 193–216. doi: 10.1080/10875549.2020.1784352

Karatas, M., Eriskin, L., Deveci, M., Pamucar, D., and Garg, H. (2022). Big data for healthcare industry 4.0: applications, challenges and future perspectives. *Expert Syst. Appl.* 200:116912. doi: 10.1016/j.eswa.2022.116912

Kazancoglu, Y., Lafci, C., Kumar, A., Luthra, S., Garza-Reyes, J. A., and Berberoglu, Y. (2023). The role of Agri-food 4.0 in climate-smart farming for controlling climate change-related risks: a business perspective analysis. *Bus. Strateg. Environ.* 2, 1–15. doi: 10.1002/bse.3629

Khamis, A., Li, H., Prestes, E., and Haidegger, T. (2019). AI: a key enabler for sustainable development goals: part 2 [industry activities]. *IEEE Robot. Autom. Mag.* 26, 122–127. doi: 10.1109/MRA.2019.2945739

Kshetri, N. (2017a). Potential roles of blockchain in fighting poverty and reducing financial exclusion in the global south. *J. Glob. Inf. Technol. Manag.* 20, 201–204. doi: 10.1080/1097198X.2017.1391370

Kshetri, N. (2017b). The economics of the internet of things in the global south. *Third World Q.* 38, 311–339. doi: 10.1080/01436597.2016.1191942

Lakner, C., Mahler, D. G., Negre, M., and Prydz, E. B. (2022). How much does reducing inequality matter for global poverty? *J. Econ. Inequal.* 20, 559–585. doi: 10.1007/s10888-021-09510-w

Leal Filho, W., Lovren, V. O., Will, M., Salvia, A. L., and Frankenberger, F. (2021). Poverty: a central barrier to the implementation of the UN sustainable development goals. *Environ Sci Policy* 125, 96–104. doi: 10.1016/j.envsci.2021.08.020

Leichenko, R., and Silva, J. A. (2014). Climate change and poverty: vulnerability, impacts, and alleviation strategies. *Wiley Interdiscip. Rev. Clim. Chang.* 5, 539–556. doi: 10.1002/WCC.287

Liang, T., and Wang, X. (2022). A statistical analysis model of big data for precise poverty alleviation based on multisource data fusion. *Sci. Program.* 2022, 1–10. doi: 10.1155/2022/5298988

Liu, H., Liu, Y., Qin, Z., Zhang, R., Zhang, Z., and Mu, L. (2021). A novel DBSCAN clustering algorithm via edge computing-based deep neural network model for targeted poverty alleviation big data. *Wirel. Commun. Mob. Comput.* 2021, 1–10. doi: 10.1155/2021/5536579

Lopez-Vargas, A., Fuentes, M., and Vivar, M. (2020). Challenges and opportunities of the internet of things for global development to achieve the united nations sustainable development goals. *IEEE Access* 8, 37202–37213. doi: 10.1109/ACCESS.2020.2975472

López-Vargas, A., Ledezma-Espino, A., and Sanchis-de-Miguel, A. (2022). Methods, data sources and applications of the artificial intelligence in the energy poverty context: a review. *Energ. Buildings* 268:112233. doi: 10.1016/j.enbuild.2022.112233

Maddikunta, P. K. R., Pham, Q. V., Deepa, N., Dev, K., Gadekallu, T. R., Ruby, R., et al. (2022). Industry 5.0: a survey on enabling technologies and potential applications. *J. Ind. Inf. Integr.* 26:100257. doi: 10.1016/j.jii.2021.100257

Masud-All-Kamal, M., and Nursey-Bray, M. (2021). Socially just community-based climate change adaptation? *Local Environ.* 26, 1092–1108. doi: 10.1080/13549839.2021.1962829

Mhlanga, D. (2021). Artificial intelligence in the industry 4.0, and its impact on poverty, innovation, infrastructure development, and the sustainable development goals: lessons from emerging economies? *Sustainability* 13:5788. doi: 10.3390/su13115788

Mhlanga, D. (2022). Financial inclusion, social exclusion, social capital, and psychological theories of poverty in the fourth industrial revolution, Digital Financial Inclusion, 285–298. Palgrave Macmillan, Cham

Mhlanga, D. (2024). The role of big data in financial technology toward financial inclusion. *Front. Big Data* 7:1184444. doi: 10.3389/fdata.2024.1184444

Mhlanga, D., and Ndhlovu, E. (2023). Digital technology adoption in the agriculture sector: challenges and complexities in Africa. *Human Behav. Emerg. Technol.* 2023, 1–10. doi: 10.1155/2023/6951879

Moshtari, M., and Safarpour, A. (2023). Challenges and strategies for the internationalization of higher education in low-income east African countries. *High. Educ.* 87, 89–109. doi: 10.1007/S10734-023-00994-1/FIGURES/1

Moyer, J. D., and Hedden, S. (2020). Are we on the right path to achieve the sustainable development goals? *World Dev.* 127:104749. doi: 10.1016/j.worlddev.2019.104749

Müller, J. M., Kiel, D., and Voigt, K. I. (2018). What drives the implementation of industry 4.0? The role of opportunities and challenges in the context of sustainability. *Sustain. For.* 10:247. doi: 10.3390/SU10010247

Nair, R., and Landani, N. (2020). Making agricultural value chains more inclusive through technology and innovation. *UNU- WIDER* 2020:e795. doi: 10.35188/UNU-WIDER/2020/795-8

Nedumaran, S., Selvaraj, A., Nandi, R., Suchiradipta, B., Jyosthnaa, P., and Bose, D. (2020). Digital integration to enhance market efficiency and inclusion of smallholder farmers: a proposed model for fresh fruit and vegetable supply chain. *Int. Food Agribusiness Manag. Rev.* 23, 319–337. doi: 10.22434/IFAMR2019.0165

Nesa Hyder, Z. (2020). Microfinance works as a tool for poverty reduction in rural Bangladesh. *Saudi J. Econ. Finance* 4, 529–533. doi: 10.36348/sjef.2020.v04i11.005

Njuguna, C., and McSharry, P. (2017). Constructing spatiotemporal poverty indices from big data. *J. Bus. Res.* 70, 318–327. doi: 10.1016/j.jbusres.2016.08.005

Obirikorang, K. A., Sekey, W., Gyampoh, B. A., Ashiagbor, G., and Asante, W. (2021). Aquaponics for improved food security in Africa: a review. *Front. Sustain. Food Syst.* 5:705549. doi: 10.3389/fsufs.2021.705549

Omomowo, K. E. (2018). Poverty in Africa, The development of Africa, *71*, 69–94). Springer, Cham

Padilla-Medina, H. A., Martínez-Nolasco, J. A., Martinez-Nolasco, C., Barranco-Gutiérrez, J. J., Gaitan, N. C., Méndez-Guzmán, H. A., et al. (2022). IoT-based monitoring system applied to Aeroponics greenhouse. *Sensors* 22:5646. doi: 10.3390/S22155646

Pérez-Peña, M. D. C., Jiménez-García, M., Ruiz-Chico, J., and Peña-Sánchez, A. R. (2021). Analysis of research on the SDGs: the relationship between climate change, poverty and inequality. *Appl. Sci.* 11:8947. doi: 10.3390/APP11198947

Phiri, M. Z., Molotja, N., Makelane, H., Kupamupindi, T., and Ndinda, C. (2016). Inclusive innovation and inequality in South Africa: a case for transformative social policy. *Innov. Dev.* 6, 123–139. doi: 10.1080/2157930X.2015.1047112

Praveena, B. A., Lokesh, N., Buradi, A., Santhosh, N., Praveena, B. L., and Vignesh, R. (2022). A comprehensive review of emerging additive manufacturing (3D printing technology): methods, materials, applications, challenges, trends and future potential. *Mater. Today Proc.* 52, 1309–1313. doi: 10.1016/j.matpr.2021.11.059

Raj, A., Dwivedi, G., Sharma, A., de Sousa, L., Jabbour, A. B., and Rajak, S. (2020). Barriers to the adoption of industry 4.0 technologies in the manufacturing sector: an inter-country comparative perspective. *Int. J. Prod. Econ.* 224:107546. doi: 10.1016/J.IJPE.2019.107546

Rohr, J. R., Sack, A., Bakhoum, S., Barrett, C. B., Lopez-Carr, D., Chamberlin, A. J., et al. (2023). A planetary health innovation for disease, food and water challenges in Africa. *Nature* 619, 782–787. doi: 10.1038/s41586-023-06313-z

Ross, S., Korostynska, O., Cordova-Lopez, L. E., and Mason, A. (2022). A review of unilateral grippers for meat industry automation. *Trends Food Sci. Technol.* 119, 309–319. doi: 10.1016/J.TIFS.2021.12.017

Saidi, Y., Labidi, M. A., and Ochi, A. (2023). Economic growth and extreme poverty in sub-Saharan African countries: non-linearity and governance threshold effect. *J. Knowl. Econ.* 1–33:e10. doi: 10.1007/S13132-023-01421-7/TABLES/10

Saleem, H., Muhammad, , Khan, B., Seyed, A., Mahdavian, M., Umar, et al. (2023). The role of technological innovation, economic policy uncertainty, and poverty reduction in attaining environmental sustainability agenda: contextual evidence from developing south and east Asian economies. *Environ. Dev. Sustain.* 2023, 1–35. doi: 10.1007/S10668-023-03919-1

Shkabatur, J., Bar-El, R., and Schwartz, D. (2022). Innovation and entrepreneurship for sustainable development: lessons from Ethiopia. *Prog. Plan.* 160:100599. doi: 10.1016/j.progress.2021.100599

Stefanidis, A., Casselman, R. M., and Horak, S. (2024). Twenty-five years of management research on poverty: a systematic review of the literature and a research agenda. *Business Ethics Environ. Responsibil.* 33, 14–39. doi: 10.1111/BEER.12503

Tamasiga, P., Ouassou, E., Houssin, , Onyeaka, , Bakwena, M., Happonen, A., et al. (2023). Forecasting disruptions in global food value chains to tackle food insecurity: the role of AI and big data analytics—a bibliometric and scientometric analysis. *J. Agric. Food Res.* 14:100819. doi: 10.1016/j.jafr.2023.100819

Tang, C. S. (2022). Innovative technology and operations for alleviating poverty through Women's economic empowerment. *Prod. Oper. Manag.* 31, 32–45. doi: 10.1111/POMS.13349

Trendov, N. M., Varas, S., and Zeng, M. (2019). Digital Technologies in Agriculture and Rural Areas, Briefing paper FAO (Issue June 2018). Available at: http://www.fao.org/3/ca4887en/ca4887en.pdf

Tripathi, A., Jain, A., Singh, A. K., Choudhary, P., Mishra, K. K., and Vashist, P. C. (2022). The internet of things in agriculture for sustainable rural development, AI, edge and IoT-based smart agriculture, 157–170. Academic Press

Trivelli, L., Apicella, A., Chiarello, F., Rana, R., Fantoni, G., and Tarabella, A. (2019). From precision agriculture to industry 4.0: unveiling technological connections in the agrifood sector. *Br. Food J.* 121, 1730–1743. doi: 10.1108/BFJ-11-2018-0747

Ukoba, K., Kunene, T. J., Harmse, P., Lukong, V. T., and Chien Jen, T. (2023). The role of renewable energy sources and industry 4.0 focus for Africa: a review. *Appl. Sci.* 13:1074. doi: 10.3390/APP13021074

UNIDO (2020). Digital transformation strategy in action: Developing a roadmap towards the fourth industrial revolution in Africa: United Nations Industrial Development Organization.

United Nations. (2015). Transforming our world: The 2030 agenda for sustainable development

Usmanova, A., Aziz, A., Rakhmonov, D., and Osamy, W. (2022). Utilities of Artificial Intelligence in poverty prediction: a review. *Sustain. For.* 14:14238. doi: 10.3390/SU142114238

Wietzke, F. B. (2020). Poverty, inequality, and fertility: the contribution of demographic change to global poverty reduction. *Popul. Dev. Rev.* 46, 65–99. doi: 10.1111/PADR.12317

Wiratama, B. F., Kurniawan, R., Mulyanto Isnaeni, M. A., Sumargo, B., and Gio, P. U. (2023). Measuring the physical infrastructure development as poverty reduction program in Kalimantan. *Indonesia. Cities* 141:104515. doi: 10.1016/j.cities.2023.104515

World Economic Forum. (2020). Unlocking Technology for the Global Goals. World Economic Forum, Available at: http://www3.weforum.org/docs/Unlocking_Technology_for_the_Global_Goals.pdf

Xu, D., Gao, Y., and Xiao, X. (2022). Precision poverty alleviation methods in the agricultural field based upon wireless communication networks and Blockchain. *Wirel. Commun. Mob. Comput.* 2022, 1–12. doi: 10.1155/2022/2687445

Yun, W. S., Ryu, W., Seo, H., Hong, W. H., and Lee, S. W. (2024). IoT-based indoor thermal environment and occupancy monitoring for energy poverty care. *Energies* 17:326. doi: 10.3390/en17020326

Zervoudi, E. K. (2020). Fourth industrial revolution: opportunities, challenges, and proposed policies, A. Grau and Z. Wang (Eds.), Industrial robotics-new paradigms 13 IntechOpen

Zhang, X. (2022). The use of ethereum blockchain using internet of things technology in information and fund management of financial poverty alleviation system. *Int. J. Syst. Assur. Eng. Manag.* 13, 1205–1215. doi: 10.1007/S13198-022-01644-Y/FIGURES/8

Zhao, Z., Ma, Y., Mushtaq, A., Rajper, A. M. A., Shehab, M., Heybourne, A., et al. (2021). Applications of robotics, artificial intelligence, and digital technologies during COVID-19: a review. *Disaster Med. Public Health Prep.* 16, 1634–1644. doi: 10.1017/DMP.2021.9

Zougmoré, R. B., Läderach, P., and Campbell, B. M. (2021). Transforming food Systems in Africa under climate change pressure: role of climate-smart agriculture. *Sustain. For.* 13:4305. doi: 10.3390/SU13084305