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Artificial Intelligence for Achieving Sustainable Development Goals: Applications, Techniques and Progress

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Abstract

Artificial Intelligence (AI) has proven to be a pivotal technology in addressing complex global challenges, particularly in the context of the United Nations Sustainable Development Goals (SDGs). These goals represent a universal call to action to end poverty, protect the planet, and ensure prosperity for all. This survey systematically explores the applications of AI in advancing sustainable development across critical domains, including agriculture and food security, healthcare, renewable energy, and climate change. By analyzing state-of-the-art AI methodologies such as machine learning, natural language processing, and computer vision, the paper highlights significant progress in these areas. Despite these advancements, challenges such as ethical considerations, data accessibility, and socio-economic inequalities persist, limiting the full potential of AI in achieving the SDGs. This review aims to provide a comprehensive and critical examination of AI's contributions to sustainable development, identify key limitations, and propose future research directions.

Keywords: Artificial Intelligence; Sustainable Development Goals; Food Security; Healthcare; Renewable Energy; Climate Change; Machine Learning.

1 | Introduction

The United Nations Sustainable Development Goals (SDGs) represent a shared vision for a sustainable and inclusive future by 2030 [1, 2]. These 17 interconnected goals address critical global challenges, including eradicating poverty and hunger, promoting health and education, ensuring access to clean energy, and combating climate change. The SDGs are critical not only for improving quality of life globally but also for maintaining the ecological and social systems that underpin human existence [3, 4]. However, progress toward these goals has been uneven, with many regions facing significant barriers that hinder sustainable development [5, 6].

Artificial Intelligence (AI) technologies, including machine learning, natural language processing, and computer vision, have shown significant promise in addressing the multifaceted challenges outlined in the SDGs [7-9]. With its ability to process vast amounts of data, uncover patterns, and make informed predictions, AI has become a critical tool in fields such as healthcare [10], agriculture [11], energy [12], and environmental conservation [13]. For instance, AI-driven tools can optimize crop yields, improve diagnostic accuracy in medicine, and enhance the efficiency of renewable energy systems. Furthermore, AI's ability to analyze vast

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amounts of data enables better decision-making [14], enabling governments and organizations to allocate resources more effectively and measure the impact of their initiatives in real-time [15].

Despite its transformative potential, the integration of AI into sustainability efforts presents unique challenges. Ethical concerns, such as bias and transparency [16], and practical limitations, including data accessibility and infrastructure disparities, must be addressed to maximize AI's impact [17, 18]. This survey examines the current applications of AI in advancing specific SDGs, with a particular focus on four key areas: agriculture and food security, healthcare, renewable energy, and climate change. It highlights the challenges and limitations faced in these domains while proposing future directions for research and development. By critically evaluating how AI can contribute to achieving these SDGs, the survey aims to bridge the gap between technological innovation and global sustainability, offering insights into how AI can effectively support sustainable development.

This survey begins with a Background section that provides an overview of the SDGs and key AI technologies in section 2. Section 3 then explores the applications of AI in four critical areas: Food Security, Healthcare, Renewable Energy, and Climate Change. Next, the Challenges, Limitations, and Future Directions section examines ethical concerns, technical barriers, and socio-economic considerations surrounding AI implementation are discussed in Section 4. Finally, section 5 shows the conclusion which summarizes the findings and highlights future research opportunities to enhance AI's impact on sustainable development.

2 | Background

2.1 | Sustainable Development Goals (SDGs)

The Sustainable Development Goals (SDGs), adopted by the United Nations in 2015, represent a global blueprint aimed at addressing the world's most urgent challenges by 2030 [1]. These 17 goals cover a broad spectrum, from reducing poverty and ensuring quality education, to combating climate change and promoting sustainable resource use [19]. Achieving these goals requires innovative, cross-sectoral approaches that integrate advanced technologies, such as AI) technologies [20].

The United Nations (UN) and researchers often group the 17 Sustainable Development Goals (SDGs) into five thematic categories to simplify the understanding and prioritization of global sustainability challenges [21, 22], these categories are social goals, environmental goals, economic goals, urban and community goals, and governance and partnership goals. Each category addresses a critical aspect of global sustainability. Social Goals focus on improving human well-being by eliminating poverty and hunger, promoting health, education, gender equality, and reducing inequalities (SDGs 1, 2, 3, 4, 5, and 10). Environmental Goals aim to protect ecosystems and combat climate change through clean energy, sustainable resource management, and biodiversity conservation (SDGs 6, 7, 13, 14, and 15). Economic Goals emphasize sustainable growth, innovation, and efficient resource use, fostering fair work conditions and industrial development (SDGs 8, 9, and 12). Urban and Community Goals center on creating inclusive, resilient, and sustainable cities and communities (SDG 11). Finally, Governance and Partnership Goals promote global collaboration, justice, and strong institutions to drive progress across all areas (SDGs 16 and 17). These 17 sustainable development goals are figured in Figure 1. These interconnected goals provide a comprehensive framework for achieving a sustainable, equitable future for all [3].

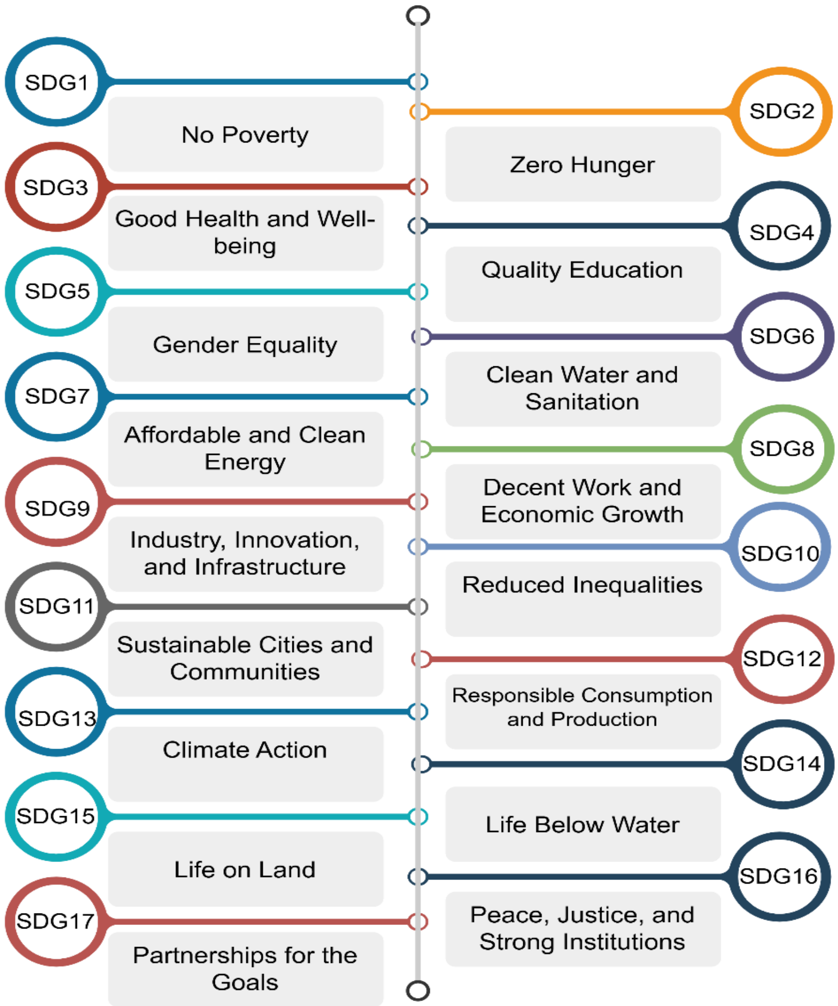

Figure 1. The 17 Sustainable development goals (SDGs).

Among the 17 SDGs, AI's transformative potential becomes especially apparent when applied to goals that demand innovative technological solutions. Some goals are particularly enhanced by AI's capabilities, including to zero hunger SDG, where AI can help revolutionize agriculture through precision farming techniques, optimize food supply chains, and mitigate food waste, thereby increasing global food security [23].in addition to, in healthcare and Well-being, AI is being applied to disease diagnosis, personalized treatment, and resource allocation, addressing critical health disparities in underserved regions [10, 24]. AI technologies also have an important role to achieving affordable and clean energy SDG, these technologies were used in optimizing energy production, storage, and consumption, facilitating the transition to renewable energy sources and ensuring sustainable energy use [25]. Furthermore, AI plays a crucial role in climate modeling, disaster prediction, and monitoring emissions, enabling more effective climate change mitigation and adaptation strategies [26].

These specific SDGs provide a clear framework for understanding AI's potential to drive significant progress in addressing global challenges. The application of AI to these areas is not only transformational but also essential for meeting global sustainability targets in a timely manner.

2.2 | Overview of Artificial Intelligence (AI)

Artificial Intelligence (AI) refers to the development of computer systems capable of performing tasks that typically require human intelligence [27]. These tasks include learning from data, recognizing patterns, making decisions, and solving complex problems [28, 29]. AI encompasses various methodologies, each suited to different types of challenges and applications. The primary AI techniques that have been widely adopted in sustainable development applications include machine learning (ML), deep learning (DL), natural language processing (NLP), and reinforcement learning (RL) [30, 31]. These techniques are figured in Figure 2.

Machine Learning (ML) allows algorithms to learn from data, making it valuable for optimizing systems in sustainable development, such as predicting crop yields in agriculture or managing electricity grids in energy systems. This foundation of data-driven prediction and optimization is further enhanced by Deep Learning (DL), a subset of ML that specializes in processing vast amounts of unstructured data like images and speech [32, 33]. Complementing these techniques is Natural Language Processing (NLP), which enables machines to interpret and interact with human language. NLP is crucial for sectors like healthcare, where it can analyze patient records, or in education, where it can help provide personalized learning experiences [33]. Figure 2 illustrates the hierarchical relationship between AI, ML, DL, and NLP. Finally, Reinforcement Learning (RL) takes decision-making a step further by training AI models through trial and error, offering optimal solutions in dynamic environments [34]. This technique is applied in areas like renewable energy management, where it can optimize grid performance, or in food distribution logistics, where it enhances supply chain decisions.

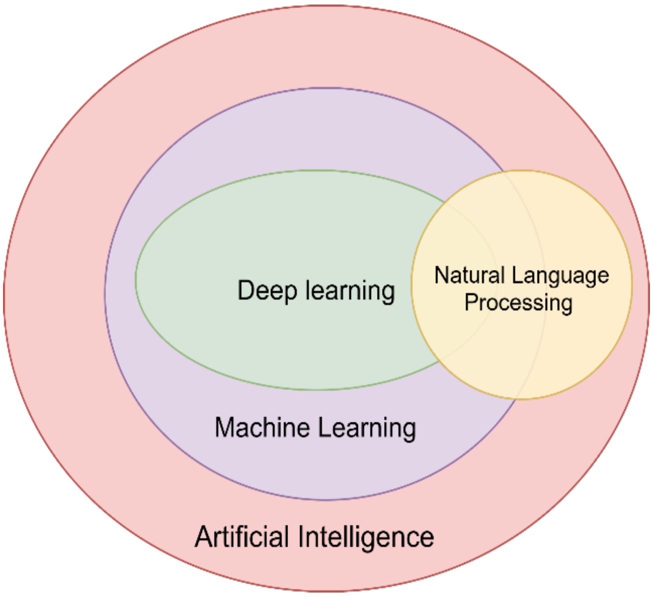

Figure 2. The hierarchical relationship between AI, ML, DL and NLP.

Together, these AI techniques enable the creation of systems that can process complex, large-scale data, identify hidden patterns, and suggest optimal solutions. The integration of AI into sustainable development efforts facilitates the more efficient use of resources, timely interventions in crisis situations, and innovative approaches to long-term sustainability.

3 | AI Applications Across Key Sectors for Achieving SDGs

In this survey, we have specifically focused on four critical areas where artificial intelligence (AI) can play a transformative role in achieving sustainability: food security, healthcare, renewable energy, and climate action. These sectors were selected due to their profound impact on global well-being and their centrality to several key SDGs.

3.1 | AI in Agriculture and Food Security

Agriculture and food security are central to global sustainability, aligning directly with SDG 2: Zero Hunger. The application of artificial intelligence (AI) in agriculture has introduced transformative changes, enabling farmers and stakeholders to optimize production processes, reduce waste, and address critical challenges such as pest control, unpredictable weather, and resource scarcity.

AI technologies have transformed agriculture by optimizing productivity and sustainability. Precision farming, powered by AI tools and sensors, enables farmers to monitor soil conditions, and predict crop health, while minimizing resource use [11, 35]. Crops farming presents a variety of difficulties. one significant danger to yield and quality is foliar disease For efficient disease control and sustainable agricultural productivity, early and accurate identification of these diseases is an essential task Deep learning models such as CNN were used to detecting the plants and crops diseases such as corn, paddy, tomato, and potato [36-38], Traditional methods of disease detection, which rely on visual examination by human experts, are often time-consuming, subjective, and prone to errors. By leveraging CNNs, AI systems can quickly and accurately identify plant diseases, saving both time and cost while reducing crop loss and waste [39].

In addition to disease detection, AI applications in agriculture extend to recommendation systems that analyze weather conditions, soil quality, and other environmental factors to provide data-driven insights [40]. These systems recommend optimal crop choices and farming practices to maximize yield and production efficiency. In addition, AI applications in agriculture have expanded to include monitoring soil health and providing actionable insights. Advanced AI systems analyze real-time soil data, such as ph levels, nutrient content, and moisture, to identify potential deficiencies or imbalances [41]. Additionally, AI-powered smart irrigation systems are transforming water management into agriculture. These systems use sensors and predictive algorithms to monitor weather patterns, soil moisture, and crop water needs [42]. Such AI-driven solutions not only enhance agricultural productivity but also promote sustainable practices across the sector by optimizing resource usage, minimizing waste, and improving the overall management of agricultural inputs.

Another promising AI application in agriculture focuses on the recognition of harmful insects and the detection of harmful weeds by leveraging advanced machine learning algorithms and computer vision techniques [43, 44]. This not only enhances crop yield but also promotes sustainable agricultural practices, ensuring that food production remains efficient and resilient to environmental challenges, which is crucial for improving global food security [45].

In the broader food security context, AI improves food distribution by predicting demand [46], streamlining supply chains [47], and optimizing logistics to reduce transport costs and delivery times. Additionally, AI technologies contribute to minimizing food waste by monitoring storage conditions and predicting shelf life, ensuring timely redistribution of surplus food [48]. Together, these innovations help create a more efficient, sustainable, and resilient food system, vital for addressing global food security challenges.

3.2 | AI In Healthcare Sector

The healthcare sector stands to benefit significantly from the integration of Artificial Intelligence (AI), particularly in achieving SDG 3: Good Health and Well-being. AI-driven tools have the capability to revolutionize disease prediction, diagnosis, and treatment by leveraging advanced data analysis techniques. For instance, The COVID-19 pandemic underscored the critical importance of Artificial Intelligence (AI), Machine Learning (ML), and Deep Learning (DL) technologies in addressing global health emergencies. This is exemplified in the research conducted by Alafif et al [49]. Due to the power of deep learning models such as CNNs in capturing features from medical images. it was used in a lot of applications, such as anatomization on breast cancer detection and diagnosis [50] in addition of the segmentation process in the detecting brain tumor [51] and the bone fractures recognition [52]. These advancements facilitate personalized treatment plans tailored to individual patient needs, improving therapeutic outcomes and reducing misdiagnoses.

AI also plays a vital role in healthcare delivery, particularly in underserved regions, by supporting telemedicine platforms and decision support systems that enable remote consultations and informed decision-making [53], which brings the essential medical services to populations with limited access to healthcare facilities. Furthermore, AI-based decision support systems assist healthcare providers in making informed clinical decisions, ensuring that even regions with a shortage of skilled professionals can deliver quality care [53, 54]. Moreover, AI streamlines healthcare systems and predicts disease outbreaks. As authors in [55] utilized sentiment analysis and machine learning techniques to predict disease outbreaks by analyzing datasets containing public sentiments expressed on platforms such as Twitter, Facebook posts, and blogs. These tools provide valuable insights into public perceptions on specific topics. Collectively, such AI applications contribute to saving lives, improving the efficiency of healthcare delivery, and increasing accessibility to advanced medical tools.

Another critical application of AI in healthcare lies in enhancing operational efficiency and streamlining workflows, thereby transforming the delivery of medical services. AI-powered systems automate routine administrative tasks, such as appointment scheduling reducing the administrative burden on healthcare professionals and allowing them to focus more on patient care [56, 57]. For example, chatbots integrated with AI can handle patient inquiries, schedule appointments, and provide follow-up reminders, improving patient engagement and reducing no-show rates [58]. These advancements underscore AI's pivotal role in transforming healthcare systems to meet the growing demands of global health challenges.

3.3 | AI In Renewable Energy Sector

The renewable energy sector is an area where AI has demonstrated transformative potential, significantly contributing to SDG 7: Affordable and Clean Energy by optimizing energy production, storage, and consumption. It improves the efficiency of renewable sources like wind, solar, and hydropower by predicting energy generation patterns and automating energy distribution, ensuring a better match between supply and demand. For instance, long short-term memory (LSTM) was used to predict the generated solar energy through Irradiance Forecasting [59], the authors used historical data related to multiple sits collected by NASA. Authors in [60] proposed an hybrid model which integrates convolutional neural network (CNN), long short-term memory (LSTM) networks, and multi-layer perceptron network (MLP) for hourly solar irradiance forecasting, and the results shows a high prediction accuracy. In the wind power forecasting sector, deep learning Gated Recurrent Unit (GRU) model was compared to some of statistical models, and the results demonstrated that GRU was the best model among others with the least possible errors and high accuracy in wind power forecasting [61]. Machine learning algorithms such as Support vector machine and ANN were used in to predict the hydropower at three Gorges Dam, China and the models shoes a high prediction accuracy [62].

In energy storage, AI addresses critical challenges by optimizing battery charging and discharging cycles, minimizing energy loss, and ensuring that surplus energy is stored for later use. Studies, such as Prediction, monitoring, and optimization the ion battery lifecycle using Data-driven-aided models [63], in addition to forecast the remaining useful life prediction for proton exchange membrane fuel cells using combined convolutional neural network and recurrent neural networks [64], those two batteries are widely used for energy storage, particularly in systems that rely on renewable energy sources like solar and wind or electric vehicles [65]. Which highlights how AI-driven algorithms improve energy storage efficiency and extend battery lifespans, making renewable energy systems more reliable and sustainable.

Furthermore, AI plays a vital role in energy grid management by balancing supply and demand in real-time, preventing shortages and minimizing waste [66]. Predictive maintenance, another key application, leverages AI to detect potential failures in renewable energy infrastructure, such as wind turbines and solar panels, before they occur [67, 68]. In this study [69], a comprehensive approach combining artificial intelligence algorithm techniques with Metaheuristic optimization algorithms was presents for anticipating and managing renewable energy sources in smart grid environments. Another application of AI techniques is the prediction of energy consumption, which helps in optimizing energy distribution, reducing waste, and ensuring a balance between supply and demand [70, 71]. By analyzing historical energy usage patterns, weather conditions, and real-time data, AI models can forecast consumption trends with high accuracy.

3.4 | AI in Climate Action

AI has emerged as a transformative tool in addressing the challenges of climate change, aligning directly with the objectives of SDG 13: Climate Action. By leveraging advanced machine learning and data analysis techniques, AI enhances climate modeling and disaster prediction, enabling policymakers to forecast climate scenarios with greater accuracy [72]. These predictive capabilities allow governments and organizations to plan proactive measures for mitigating the impacts of extreme weather events, such as floods and hurricanes. Researchers in [73, 74] explored the reliability of flood warning forecasts based on deep learning models, a notable accuracy. while authors in [75] applied Bidirectional Long Short-Term Memory network to predict the drought.AI-powered models analyze vast amounts of environmental data, including satellite imagery, atmospheric readings, and historical patterns, anticipating potential disasters and informing early warning systems, saving lives and/or reducing economic losses [76].

In addition to disaster prediction, AI supports resource management and sustainable practices critical to combating climate change. For example, AI-driven solutions and IoT systems for optimizing water usage in agriculture [77] , track deforestation rates through real-time satellite monitoring [78], and enhancing Forest-fire prediction systems [79]. AI also plays a pivotal role in urban planning by modeling energy-efficient cities and predicting the carbon footprint of infrastructure development [80, 81].

A significant contribution of AI to climate action lies in its role in reducing greenhouse gas emissions. AI technologies facilitate carbon capture and storage (CCS) by optimizing capture processes and monitoring emissions [82]. Through these applications, AI not only supports mitigation efforts but also strengthens adaptation strategies, enabling communities to build resilience to the inevitable impacts of climate change. As these technologies evolve, they hold immense potential to drive a sustainable and climate-conscious future.

4 | AI Challenges, Limitations, and Future Directions in Achieving SDGs

AI, while offering transformative potential, faces several ethical challenges that need to be addressed. One key issue is AI bias [83], which can arise from biased data, leading to unfair or discriminatory outcomes in areas like healthcare, hiring, and law enforcement [84, 85]. Lack of transparency in AI decision-making also poses concerns, as many AI models, particularly deep learning algorithms, operate as "black boxes," making it difficult to understand how they arrive at decisions [86]. These ethical challenges demand the development of fair, transparent, and accountable AI systems to ensure equitable outcomes.

From a technical perspective, AI development is hindered by issues such as limited data availability and the need for vast, high-quality datasets [87]. In many cases, data might be incomplete, biased, or unavailable, impacting the accuracy and reliability of AI models especially in the critical sectors such as medical field [88]. Additionally, computational power remains a barrier, as training advanced AI models, particularly those requiring large-scale deep learning techniques demands significant processing power and energy resources [89]. Overcoming these technical limitations requires advancements in data collection methods and more efficient computational approaches.

Socio-economic barriers also play a critical role in limiting AI's global impact [90]. In many developing countries, access to AI technologies and the necessary infrastructure is limited, which may exacerbate inequalities[91] . The digital divide, lack of skilled professionals, and high costs of AI technologies further contribute to these challenges. However, promising future directions include the development of explainable AI, which seeks to make AI systems more transparent, interpretable, and accountable [92, 93]. This is crucial in building trust among users and ensuring ethical decision-making, especially in sensitive areas such as healthcare, law enforcement, and environmental policy. Explainable AI can help demystify the 'black box' nature of many current models, allowing stakeholders to understand the rationale behind AI-generated insights or predictions [94].

Additionally, Cross-sector collaborations between governments, industries, academic institutions, and non-governmental organizations (NGOs) hold significant potential for addressing global challenges by combining expertise, resources, and perspectives. Such partnerships can accelerate advancements, like deploying smart grid technologies or tailoring AI solutions to support vulnerable populations [95]. Furthermore, democratizing access to AI through open datasets, and affordable computing infrastructure can empower communities in developing regions. These efforts pave the way for a more inclusive and ethical future, enabling AI to make a greater impact on achieving sustainable development goals [96].

5 | Conclusion

Artificial intelligence holds immense potential to drive progress toward achieving the Sustainable Development Goals (SDGs), particularly in critical areas such as food security, healthcare, renewable energy, and climate action. Through the application of AI technologies, we are witnessing transformative changes in how we approach complex global challenges, enhancing productivity, efficiency, and sustainability across various sectors. AI's ability to analyze vast datasets, predict outcomes, and optimize processes offers unprecedented opportunities for improving resource management, healthcare delivery, and environmental protection. However, the widespread adoption of AI is not without challenges. Ethical concerns such as AI bias and lack of transparency, technical limitations including data availability and computational power, and socio-economic barriers like accessibility in developing countries need to be addressed to ensure equitable and responsible AI deployment. Overcoming these obstacles will require collaborative efforts among policymakers, technologists, and global stakeholders to create inclusive, transparent, and effective AI systems that benefit all. Finally, the future of AI in achieving the SDGs appears promising. Advancements in explainable AI, improved data collection methods, and cross-sector collaborations hold the key to overcoming current limitations. By continuing to innovate and address these challenges, AI can play a pivotal role in building a more sustainable and equitable future.

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Data Availability

The datasets generated during and/or analyzed during the current study are not publicly available due to the privacy-preserving nature of the data but are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that there is no conflict of interest in the research.

Ethical Approval

This article does not contain any studies with human participants or animals performed by any of the authors

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