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Impact of Artificial Intelligence on Environment from the perspective of Sustainable Development Goals: A Review

Pooja Soni [1*], Dr. Jayashri Vajpai [2], Ravi Soni[3]

[1] poojavsoni@gmail.com (PhD Scholar EE Department, MBM University-Jodhpur)

[2] jayashrivajpai@gmail.com (Professor, EE Department, MBM University-Jodhpur)
[3] ravi.soni@jietjodhpur.ac.in (Assistant Professor, EE Department, JIET- Jodhpur)

*Contact: poojavsoni@gmail.com,

Abstract

Artificial Intelligence (AI) has permeated into diverse sectors with the gradual technological advancements, primarily with the goal of developing automated techniques and processes. The potential of AI to contribute towards achieving sustainable development has been significant, though the resulting ecological impact predominantly in terms of energy consumption and electronic waste has raised considerable concerns. This paper aims to explore the environmental implications of AI adoption, largely within the framework of Sustainable Development Goals (SDGs) as defined by the United Nations. It addresses the impact of AI towards achieving SDGs 7 (Affordable and Clean Energy), 12 (Responsible Consumption and Production) and 13 (Climate Action), with an objective to evaluate the role of AI for enhancing energy efficient systems, waste management and climate change mitigation methods. Moreover, it also highlights the various challenges posed by AI adoption, like e-waste generation and energy intensive AI model training, while proposing strategies to mitigate these adverse impacts. The findings underscore the importance of leveraging renewable energy sources, adopting energy efficient algorithms and adopting a circular economy for AI hardware usage and management.

Keywords: Artificial Intelligence, Environmental Impact, Sustainable Development Goals, Energy Consumption, E-Waste, Circular Economy, Climate Action, AI for Sustainability, SDGs, Renewable Energy, Energy-Efficient AI

1. Introduction

The conjunction of Artificial Intelligence (AI) and sustainability is a crucial theme for contemporary research, as AI technologies continue to revolutionize various sectors and industries worldwide. Even though AI can catalyze progress towards achieving the United Nations Sustainable Development Goals (SDGs), more and more of its potential negative environmental impacts are being realized. The SDGs defined in 2015 provide a global structure for addressing critical challenges such as sustainable energy, climate change and responsible consumption. Nevertheless, the adoption of AI technologies must also be surveyed for its environmental consequences, particularly in terms of energy consumption and electronic waste (e-waste), both of which present significant environmental concerns.

This study explores the environmental implications of AI through the lens of SDGs, particularly focusing on SDGs 7 (Affordable and Clean Energy), 12 (Responsible Consumption and Production) and 13 (Climate Action) as depicted in figure 1 below. While AI can offer considerable benefits to these goals, especially through improved energy efficiency, waste reduction and climate monitoring; it also comes with significant environmental costs. The production of hardware and the training of AI models contribute to high energy demands and the rapid obsolescence of technology aggravates the global e-waste crisis.

Figure 1: Sustainable Development Goals (SDGs) defined by The United Nations Educational, Scientific and Cultural Organization (UNESCO) **[Image reference:** https://sdgs.un.org/goals**]**

The major aim of this paper is to review the ecological impact of AI, outline and highlight its contributions to sustainable development and propose strategies to mitigate its adverse effects. By assessing some relevant real-world case studies and cutting-edge research, the opportunities and challenges associated with AI's role in sustainable development have been identified.

2. Methodology adopted

The methodology followed in this paper comprises a review of contemporary literature on AI's role in achieving the SDGs and its impact on environment. The review process included a study of the recent research papers published on the theme from year 2020 to 2025. The papers were identified from reputed academic journals and conferences related to AI, environmental sustainability and sustainable development goals. The databases of IEEE Xplore, Google Scholar and Springer were searched using different keywords like "AI and its environmental impact", "AI and SDGs", "AI based energy consumption" and "circular economy and AI".

The selected papers were then examined to assess the real-world applications and case studies of AI in promoting sustainability including various aspects, namely waste management, energy optimization and climate change mitigation methods. The environmental costs of AI adoption and deployment, specifically energy usage and hardware disposal were also studied.

The outcomes from the referred studies were then synthesized to relate the contributions of AI to specific SDGs in addition to the challenges posed by AI and its allied technologies in terms of environmental sustainability. This study also identifies strategies for mitigating the aforementioned challenges.

Followed by the findings, recommendations have been suggested to optimize AI adoption for enhanced sustainable development that includes the usage of energy-efficient algorithms, data centres powered by renewable energy and adoption of circular economy strategies in hardware production and disposal.

3. AI and its impact on Sustainable Development Goals

3.1 AI for Clean Energy (SDG 7: Affordable and Clean Energy)

AI techniques play an instrumental role in optimizing renewable energy systems, like solar and wind energy, by forecasting energy demand, managing power grids and improving the energy storage paradigms. AI-powered smart grids can largely balance energy supply and demand in real-time scenarios, integrate diverse renewable energy sources efficiently and reduce energy waste [4]. AI and the allied technologies can significantly contribute towards achieving SDG 7 that aims to ensure a widespread access to cost-effective, reliable, sustainable and modern energy. AI can also be used for predictive maintenance in renewable energy infrastructure, reducing downtime and improving the overall system efficiency.

In addition to the aforementioned, the usage of AI techniques in transportation and logistics sector expedites the optimization of electric vehicles (EVs), reducing dependence on the conventional fossil fuels, thereby assisting the transition to green mobility. For instance, route optimization and battery management systems in EVs help reduce energy consumption and carbon emissions [6].

3.2 AI for accountable Consumption and Production (SDG 12: Responsible Consumption and Production)

Judicious adoption of AI methods can contribute to achieve the goals set under SDG 12 that underlines sustainable consumption and production strategies. AI application in waste management have the potential to transform waste handling, sorting and recycling. AI-driven robotic sorting systems in recycling plants can greatly enhance the efficiency of material recovery, thereby separating valuable materials from waste effectively [7], [8].

The following table 1 lists the significant contributions of AI to the SDGs and the related environmental challenges:

Table 1: AI's Contributions to Sustainable Development Goals (SDGs) and related Environmental Challenges

SDG	AI Contribution	Environmental Challenges	Strategies for Mitigation
SDG 7: Affordable and Clean Energy	- Optimization of renewable energy systems (solar, wind) via predictive algorithms. - Smart grids for efficient energy distribution. - AI-driven electric vehicle route optimization and battery management.	- High energy consumption during training of AI models. - Increased power demand in data centers.	- Use of energy-efficient AI algorithms (Green AI). - Renewable energy-powered data centers. - AI for predictive maintenance of renewable energy infrastructure.
SDG 12: Responsible	- AI-driven recycling and waste management (e.g.,	- E-waste generation from rapidly obsolete	- Circular economy principles for AI hardware

Consumption and Production	robotic sorting). - Supply chain optimization to reduce resource waste.	AI hardware. - Resource-intensive AI model training.	(e.g., refurbishing, recycling). - Efficient algorithms to reduce computational needs. - Promoting sustainable AI hardware design and long lifecycles.
SDG 13: Climate Action	- AI models for climate predictions and disaster management. - AI-based carbon capture technologies. - Real-time carbon emission monitoring.	- Significant carbon emissions from AI model training. - Increased energy consumption in AI-driven climate solutions.	- Optimization of AI models for energy efficiency. - Use of renewable energy for AI-driven climate initiatives. - AI for real-time emissions reduction and carbon footprint tracking.

Furthermore, AI can improve supply chain management by optimizing resource utilization, reducing waste and lowering carbon emissions. In the manufacturing sector, AI-empowered predictive maintenance and resource optimization can help reduce energy and material waste, contributing to more sustainable production processes [9], [10]. By enhancing the production systems' efficiency, AI plays a significant role in promoting the circular economy, where resources are reused, recycled and repurposed. Also, in addition to SDGs 7, 12 and 13; the role of AI in relation to SDG 9 that corresponds to Industry, Innovation and Infrastructure has become more evident in the post-COVID era.

3.3 AI for Climate Action (SDG 13: Climate Action)

AI is an indispensable tool for climate action, relating and contributing to SDG 13 by supporting efforts to mitigate and adapt to climate change. AI models can process large datasets from sensors and satellites, enabling accurate predictions of climatic trends and extreme weather events [11], [12]. These AI models assist the governments and organizations to a large extent in making data-driven informed decisions for issues pertaining to climate adaptation and disaster management.

AI also benefits in carbon capture technologies by optimizing the efficacy of capturing and storing CO_2 from the atmosphere. Furthermore, AI-powered platforms can monitor carbon emissions in real-time, helping establishments reduce their environmental footprints and adhere to the standardized international climate agreements [13].

The following table showcases specific AI methods and their application to sustainable development, gauging the breadth of AI's potential in promoting and enhancing sustainability.

Table 2: Summary of AI Techniques and Their Applications for Sustainable Development

AI Technique	**Application in Sustainable Development**	**Example**	**Impact on SDGs**
Machine Learning (ML)	- Optimizing renewable energy production. - Predictive maintenance of infrastructure. - Waste management automation.	- ML-based optimization of solar panel efficiency. - AI for predictive maintenance of wind turbines.	SDG 7: Affordable and Clean Energy. SDG 12: Responsible Consumption and Production.

Deep Learning	- Climate prediction modeling. - Energy-efficient AI models. - Real-time carbon emission monitoring.	- Climate forecasting using deep neural networks. - Deep learning models for reducing energy consumption in data centers.	SDG 13: Climate Action.
Reinforcement Learning (RL)	- Energy optimization in smart grids. - AI for efficient transportation systems (EV route optimization).	- RL-based energy distribution in smart grids. - EV route optimization using RL for energy savings.	SDG 7: Affordable and Clean Energy. SDG 13: Climate Action.
Computer Vision	- Robotic waste sorting and recycling. - Agriculture monitoring for sustainable practices.	- AI-driven robotic arms for sorting recyclable materials. - Computer vision for crop health monitoring.	SDG 12: Responsible Consumption and Production. SDG 2: Zero Hunger (related to sustainable agriculture).
Natural Language Processing (NLP)	- Environmental awareness and advocacy. - AI for policy recommendations on sustainability.	- NLP models for analyzing environmental reports. - Text mining for sustainability insights from research papers.	SDG 13: Climate Action. SDG 16: Peace, Justice and Strong Institutions (policy analysis).

4. Cumulative Environmental Impact of AI

Though AI holds boundless promise for sustainable development, it is also associated with substantial environmental costs, mainly in the form of energy consumption and e-waste generation.

4.1 Energy Consumption of AI Models

Training massive AI models, predominantly deep learning algorithms, is energy-intensive. Data centers that run these models involve substantial computational resources, leading to high electricity consumption. Research indicates that training a single AI model can lead to carbon emissions comparable to those of multiple automobiles over their entire lifetimes [14]. The use of fossil-fuel-based electricity in data centers aggravates the environmental impact, whereas transitioning to renewable energy sources can considerably lower down carbon emissions [15].

4.2 E-Waste and Hardware for AI

The manufacturing and disposal of AI hardware contribute to the rising issue of e-waste. High-performance computing hardware, such as GPUs and TPUs, has a relatively short lifespan due to the rapid advancement of technology. On obsolesce of AI hardware, it often ends up in landfills, where it contributes to environmental pollution [16].

For minimization and mitigation of the mounting e-waste, a shift towards a circular economy for AI hardware is essential, which includes recycling, refurbishing and designing hardware with longer lifespans. Additionally, manufacturers could also implement take-back programs and reassure hardware reuse [17].

The following Table 3 enlists some real-world case studies to illustrate the impact of AI in encouraging sustainability.

Table 3: Case Studies of AI Implementation for Sustainability and Their Outcomes

Case Study	AI Application	Outcome	Relevant SDG(s)
Google DeepMind (Energy Efficiency in Data Centers)	AI for optimizing energy use in data centers.	Reduced energy consumption by 40%, leading to substantial carbon footprint reduction.	SDG 7: Affordable and Clean Energy.

IBM Green Horizons (Air Pollution Prediction)	AI for forecasting air pollution and advising mitigation strategies.	Improved air quality management and policy implementation in major cities.	SDG 13: Climate Action.
Carbon Clean (AI for Carbon Capture)	AI to optimize carbon capture systems in industrial plants.	Enhanced carbon capture efficiency by 30%, reducing emissions.	SDG 13: Climate Action.
Microsoft's AI for Earth (Conservation and Monitoring)	AI models for wildlife monitoring, land conservation and environmental protection.	Increased efficiency in tracking deforestation and wildlife habitats.	SDG 15: Life on Land. SDG 13: Climate Action.
Waste Management with ZenRobotics (AI Sorting System)	AI-powered robotic systems for sorting recyclables in waste management.	Increased efficiency in recycling, reduced landfill waste.	SDG 12: Responsible Consumption and Production.

5. Approaches for Mitigating the Environmental Impact of AI

Numerous strategies can be used to reduce the impact of AI on environment while maximizing its contribution towards sustainable development.

5.1 Green AI and Energy Efficient Algorithms

Green AI refers to the development of energy efficient hardware and lightweight AI algorithms that need less computational power, thereby reducing the overall energy consumption. Techniques such as model pruning, quantization and knowledge distillation can be employed to make AI models more efficient without sacrificing performance [18]. Development of such energy-efficient algorithms and hardware is a critical step in reducing the environmental impact of AI systems.

The table 4 below focuses on the impact of AI adoption on environmental, specifically in terms of energy consumption and recommends approaches for minimizing the energy footprint.

Table 4: Energy Consumption in AI Model Training and Mitigation Strategies

AI Model/Activity	**Energy Consumption (Estimated)**	**Environmental Impact**	**Mitigation Strategies**
Training Large Deep Learning Models	- Up to 10,000 kWh per model for training large-scale models (e.g., GPT-3)	High energy demand, significant carbon emissions.	- Use of energy-efficient hardware (e.g., TPUs). - Model pruning and optimization.
Data Center Operations	- Data centers may consume between 1.5-3% of global electricity (depending on region and usage).	High energy consumption leads to increased greenhouse gas emissions, especially if powered by fossil fuels.	- Transitioning to renewable energy sources. - Cooling optimization using AI.
AI in Climate Modeling	- Significant energy use, especially with long-term simulation models.	Increased computational resource demand, leading to high energy consumption.	- Use of energy-efficient algorithms for modeling. - Cloud computing solutions with renewable energy.

5.2 Renewable Energy Integration of Data Centers

AI data centers powered with renewable energy would be one of the most effective ways to mitigate AI's carbon footprint. By leveraging solar, wind and hydropower as an alternative to fossil-fuel based conventional approaches, AI systems can operate in an environmentally friendly manner. Also, an incorporation of energy storage systems can help balance the intermittent nature of renewable energy, thereby ensuring a steady power supply [19].

This table summarizes practical strategies that can help reduce AI's environmental footprint.

Table 5: Key Strategies for Reducing the Environmental Impact of AI

Strategy	Description	Potential Benefits
Energy-Efficient Algorithms	Develop AI models and algorithms that require less computational power.	Reduces energy consumption and the environmental impact of model training.
Use of Renewable Energy	Power AI-driven data centers and infrastructure with renewable energy.	Minimizes carbon footprint of AI systems, leading to reduced environmental impact.
Circular Economy for AI Hardware	Promote the reuse, recycling and longer lifespans of AI hardware components.	Reduces e-waste and the need for constant hardware production, reducing resource extraction and waste.
Optimization of Model Training	Use techniques such as knowledge distillation, model pruning and quantization to reduce model size and energy use.	Significantly lowers energy usage for AI model training and inference.
AI-Powered Energy Monitoring	Deploy AI systems for continuous monitoring of energy consumption and optimization of energy use in real-time.	Increased efficiency in data centers and industrial operations, leading to reduced energy waste.

5.3 Circular Economy and Management of E-Waste

To address the increasing e-waste problem, AI hardware should be designed and developed for modularity and recyclability. By adopting circular economy principles, the hardware can be reused, refurbished, or recycled and the lifespan of AI systems can be extended thus reducing the electronic waste generated [20].

Also,

6. Conclusion

AI has immense potential to considerably contribute towards achieving the Sustainable Development Goals, particularly in the areas of clean energy, responsible consumption and climate action. However, the environmental impact of AI, predominantly in terms of energy consumption and e-waste, must be judiciously managed to ensure that AI and its allied technologies are used in a sustainable manner. By adopting approaches such as energy-efficient algorithms, renewable energy-powered data centers and circular economy practices for hardware usage, the adverse environmental impacts of AI can be mitigated. Furthermore, AI has enormous potential to play a pivotal role in enhancing and advancing sustainability, provided that it prioritizes environmental considerations through the evolving development and deployment of AI hardware and algorithms.

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