



Environmental Implications of Artificial Intelligence: Balancing Ecological Costs and Sustainable Growth Pathways

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ABSTRACT

Artificial Intelligence (AI) is transforming multiple sectors; however, its environmental implications require critical examination. The training and deployment of large-scale AI models demand significant computational power, resulting in high energy consumption, increased carbon emissions, and growing electronic waste. Hardware production further intensifies ecological degradation through resource-intensive processes. At the same time, AI presents substantial opportunities for sustainable growth, including energy-efficient algorithms, renewable-powered data centres, precision agriculture, climate modelling, and optimised resource management. This study provides a structured review of the positive and negative environmental implications of AI and analyses how these implications influence sustainable development pathways. The findings highlight the dual role of AI as both a contributor to environmental pressure and a strategic tool for sustainability transformation. The paper concludes that responsible AI governance, energy-efficient innovation, and renewable integration are essential to ensure that AI supports long-term sustainable growth

INTRODUCTION

Artificial intelligence (AI) has flourished in all domains like medicine, finance, intelligent transportation, education, legislation, industrial automation, predictive maintenance, agriculture, energy conservation, etc. In the early 2000s witnessed the convergence of big data and high-computing resources, which enabled the establishment of higher-level AI systems, resulting in impressive advancements in computer vision, speech recognition, and autonomous vehicles (Saravanan et al., 2025). Although AI has remarkable upliftment in all the domains mentioned above, its widespread acceptance or adaptability has been hindered by its lack of transparency and trustworthiness. In many instances, computer scientists and AI model developers were not held accountable for the outcomes or decisions generated by the systems they created and deployed.

Furthermore, all the applications developed and deployed in today's digital environment are transdisciplinary, amalgamating concepts from different technologies to provide a sustainable, automated, global solution. AI systems depend heavily on vast computational power, massive datasets, and energy-intensive infrastructure, all of which exert significant environmental impacts. The implications of AI have both exacerbated and mitigated environmental problems. The Positive Implications, such as Climate Action, Disaster Risk Reduction, Ecosystem Monitoring, Sustainable Agriculture, Water and Urban Management, lead to the use of AI. The Negative Implications, like High energy consumption, Resource Depletion, Water Usage, Electronic waste, and Unequal Distribution, negatively impact the environment. The AI pathway to sustainable growth involves utilising AI to optimise resource utilisation, enhance energy efficiency through smart grids and building management, and inform urban planning with data-driven insights for improved efficiency and climate resilience. Moreover, AI applications in areas such as optimising renewable energy systems, precision agriculture, climate modelling, and resource management highlight its potential as a driver of environmental sustainability. Striking a balance between technological advancement and ecological responsibility is essential to ensure that AI supports a sustainable future.

Despite growing discussions on Sustainable AI and green computing, the literature remains fragmented between studies examining the environmental costs of AI and those emphasising its sustainability benefits. There is limited integrative analysis that systematically evaluates how these opposing implications shape sustainable growth pathways. This lack of balanced synthesis creates uncertainty for policymakers and organisations seeking to align AI adoption with environmental responsibility. Therefore, this study aims to provide a structured examination of AI's environmental implications and their influence on sustainable growth.

LITERATURE RIVIEW

Artificial intelligence is the widely accepted technology that was adopted in various domains such as Logistics, education, supply chain management, marketing, purchase decision making and etc. The literature related to various domains is listed in the following summary.

The paper titled “Sustainable AI: Environmental Implications, Challenges and Opportunities” by Carole-Jean Wu et al. (2022) discusses the operational and manufacturing carbon footprint of AI computing, offering an end-to-end analysis of how hardware–software design and large-scale optimisation can lower AI’s environmental impact. Drawing on industry experiences, the study identifies major challenges and suggests critical directions for future development across multiple dimensions of AI. Similarly, Dipti Chauhan et al.

(2024), in “Sustainable AI: Environmental Implications, Challenges and Opportunities,” emphasise that data centres and cloud infrastructures supporting AI significantly contribute to global energy consumption and carbon emissions. They point out that the processing, transmission, and storage of vast data volumes further intensify carbon output, while also examining the environmental opportunities and challenges linked with AI adoption.

The work “Sustainable AI: AI for sustainability and the sustainability of AI” by Aimee van Wynsberghe (2021) conceptualises Sustainable AI as a movement aimed at reforming the entire lifecycle of AI, ranging from idea generation, training, and re-tuning to implementation and governance towards ecological sustainability and social justice.

This perspective stresses that Sustainable AI is not only about applications but also about the broader sociotechnical system. In the paper “Considering the Environmental Impacts of Generative AI to Spark Responsible Development,” MIT Researchers (2024) caution that enthusiasm around generative AI often neglects associated social and environmental costs. They argue for comprehensive assessments, innovation, coordination, and stakeholder collaboration to guide responsible development.

Additionally, “A review of green artificial intelligence: Towards a more sustainable future” by Veronica Bolon-Canedo et al. (2024) highlights the importance of regulations in promoting green AI and outlines future pathways for sustainable machine learning. The article underlines the need to align AI practices with environmental goals, fostering energy-efficient systems and a greener technological landscape.

Statement of the Problem

Artificial Intelligence (AI) has rapidly expanded across industries, offering transformative solutions in climate modelling, energy management, agriculture, logistics, and resource optimisation. While AI is increasingly promoted as a driver of sustainable development, its operational infrastructure relies heavily on energy-intensive data centres, large-scale computational processing, and resource-demanding hardware production. These factors contribute to rising electricity consumption, carbon emissions, water usage, electronic waste, and mineral extraction pressures.

Existing research has examined either the environmental costs of AI systems or the potential of AI to support sustainability initiatives. However, there remains a lack of integrated analysis that critically evaluates both the positive and negative environmental implications of AI within a unified framework. This fragmented perspective creates uncertainty regarding whether AI ultimately advances or undermines sustainable growth.

Furthermore, as AI adoption accelerates globally, policymakers and organisations face challenges in balancing technological innovation with ecological responsibility. Without a structured understanding of AI's dual environmental impact, sustainable growth strategies risk being incomplete or technologically biased.

Therefore, the core problem addressed in this study is the absence of a balanced and comprehensive examination of AI's environmental implications and their influence on sustainable growth pathways. This study seeks to bridge this gap by analysing both the ecological costs and sustainability benefits of AI within a consolidated framework.

Objectives

- To analyse the positive and negative environmental implications of AI
- To evaluate how the AI in environmental implications influences the sustainable pathways.

METHODOLOGY

This study adopts a qualitative review approach. The secondary data analysing peer-reviewed literature published on AI and environmental sustainability.

RESULT AND DISCUSSION

To identify the positive and negative environmental implications of AI

AI carries both beneficial and adverse implications for the environment. In the context of artificial intelligence, the term environment refers to the conditions or settings within which an AI system operates. This may include the physical environment, digital ecosystems, and virtual spaces where AI models and algorithms are applied. With this understanding, the following section highlights the positive implications of AI.

The positive environmental implications are:

AI can improve the understanding of extreme weather and model climate change scenarios, and also significantly enhances climate modelling and risk assessment by improving the accuracy and resolution of climate projections, processing vast datasets from diverse sources, and enabling faster identification of climate hazards. AI can help optimise resource utilisation and improve the management of resources across various industries. The environmental implications of AI refer to the efficient use of energy, materials, and computational power to reduce waste and minimise ecological impact. AI technologies can enhance energy efficiency in data centres, streamline manufacturing and supply chains, and improve transportation through smart route planning. AI can forecast and manage energy demands, optimise heating and cooling systems, and improve the efficiency of power grids. AI highlights how artificial intelligence can both consume and conserve energy. On one hand, training large AI models requires massive computational power, leading to high electricity usage and carbon emissions. On the other hand, AI can significantly improve energy efficiency by optimising data centre cooling, reducing redundant computations, and managing workloads effectively. AI can enhance product life-cycle assessments and improve the accuracy of supply chain emissions calculations. It optimises logistics by predicting demand, reducing overproduction, and minimising transportation routes, which lowers fuel consumption and carbon emissions. It also improves inventory management, cutting down waste of raw materials and finished goods.

The negative environmental implications are:

Training large AI models and running AI-powered systems requires significant amounts of electricity, primarily in large data centres. The implications of increased greenhouse gas emissions from powering AI systems with fossil fuels. This heavy energy consumption, often sourced from fossil fuels, leads to significant greenhouse gas. The electricity used for AI often comes from non-renewable fossil fuels, leading to substantial carbon emissions and contributing to climate change. Data centres that power AI models rely heavily on water for cooling their servers. Massive volumes of water are consumed to prevent overheating, especially in regions with large-scale AI infrastructure. Data centres need large amounts of water for cooling, which can strain freshwater resources. It is often implied by the environment that E-waste is the term to describe things like air conditioners, televisions, and personal electronic devices, such as cell phones and laptops, when they are thrown away. These devices often contain hazardous or toxic materials that can ham human health or the environment if they're not disposed of properly. Besides those potential harms, when appliances like washing machines and high-performance computers wind up in the trash, the valuable metals inside the devices are also wasted taken out of the supply chain instead of being recycled. The mining of rare earth minerals and metals needed for AI chips can lead to soil erosion and other environmental damage.

To examine how the AI in environmental implications influences sustainable pathways

Artificial intelligence is shaping the future of sustainability with profound and complex environmental implications that warrant careful attention and action. On one hand, AI's exponential expansion is driving unprecedented demand for energy and water to power vast data Centers and complex models, often reliant on fossil fuel-based grids, which leads to increased greenhouse gas emissions and poses risks to ecosystems if unmanaged. However, this very technology is also a potent force for good: it is powering innovations in climate modelling, energy management, and biodiversity conservation.

AI systems optimise supply chains for resource efficiency, enable precision agriculture that boosts yields while minimising inputs, and manage renewable energy grids for higher efficiency and resilience, supporting the shift towards low-carbon societies. In areas like air and water quality management, AI-driven sensor networks process massive amounts of real-time data, allowing rapid, targeted interventions to improve public health and reduce pollution. AI is at the forefront in waste management, enabling smart recycling and more efficient resource use, while in the Global South, AI-driven energy strategies help bridge gaps in equitable access to clean energy.

Yet, the escalating resource demands of AI raise pressing questions: how can society harness AI's transformative environmental benefits without amplifying its carbon and water footprint? The path forward calls for a balanced strategy prioritising energy-efficient hardware and algorithms, investing in renewable energy for digital infrastructure, and fostering collaborative frameworks that ensure equitable, responsible, and human-centred AI deployment. Ultimately, integrating sustainability at every stage of the AI lifecycle and promoting global cooperation will be critical for leveraging AI as a catalyst for a greener, fairer future rather than a source of new planetary risk

CONCLUSION AND RECOMMENDATION

In conclusion, the environmental implications of artificial intelligence are marked by a distinct duality that both challenges and advances sustainability efforts. On the positive side, AI enables significant progress in environmental monitoring, climate modelling, and optimised resource management, empowering industries to reduce waste, lower emissions, improve the efficiency of renewables, and streamline logistics for a greener future. These advancements strengthen climate resilience, improve supply chain transparency, and support conservation efforts across sectors. However, AI's rapid growth has dramatically increased global electricity demand, with power-hungry data centres relying heavily on fossil fuels, thereby accelerating greenhouse gas emissions and contributing to climate change.

The extensive use of water for cooling servers and the rising tide of electronic waste, compounded by the mining of rare earth elements for hardware, add significant environmental pressures. The balance between AI's environmental benefits and costs highlights a clear path forward: sustainable innovation in AI demands urgent investments in energy-efficient algorithms and hardware, widespread adoption of renewable energy, responsible lifecycle

management of electronics, and strong, collaborative governance frameworks to ensure equitable and ethical outcomes. Ultimately, the intersection of AI and the environment calls for ongoing vigilance, leveraging AI's transformative capabilities while continuously minimising its ecological footprint to realise both technological and planetary

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