

A CONCEPTUAL MODEL FOR GREEN AI ADOPTION IN SUSTAINABLE HEALTHCARE SYSTEMS

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ABSTRACT

The rapid integration of Artificial Intelligence (AI) in healthcare has revolutionized diagnosis, treatment, and administrative efficiency. However, the increasing computational demands of AI systems raise concerns about their environmental impact, particularly in terms of energy consumption and carbon emissions. This review paper explores the concept of Green AI and its relevance in promoting sustainable digital transformation in healthcare systems. By synthesizing existing literature, the study examines key drivers, applications, challenges, and frameworks for adopting energy-efficient and environmentally responsible AI solutions. The paper proposes a conceptual framework integrating technological, organizational, and environmental dimensions to guide sustainable AI adoption in healthcare. The findings highlight that Green AI can significantly enhance healthcare efficiency while minimizing environmental footprints, provided that policy support, ethical considerations, and infrastructure readiness are ensured.

Keywords: Green AI, Sustainable Healthcare, Digital Transformation, Artificial Intelligence, Energy Efficiency, Healthcare 4.0

INTRODUCTION

The healthcare sector is undergoing rapid digital transformation driven by the integration of Artificial Intelligence (AI) technologies. AI has significantly enhanced healthcare delivery by improving diagnostic accuracy, enabling predictive analytics, and facilitating personalized treatment. From clinical decision support systems to robotic surgeries and telemedicine, AI-driven innovations are reshaping the efficiency and effectiveness of healthcare systems. However, the increasing reliance on AI has also raised critical concerns regarding its environmental impact, particularly in terms of high energy consumption, carbon emissions, and resource utilization associated with large-scale data processing and computational infrastructure.

In response to these concerns, the concept of **Green AI** has emerged as a sustainable approach to AI development and deployment. Green AI emphasizes the design of energy-efficient algorithms, optimization of computational resources, and reduction of the carbon footprint associated with AI systems. Unlike traditional AI, which prioritizes performance and accuracy often at the cost of high computational power, Green AI seeks to balance performance with environmental sustainability. This shift is particularly important in healthcare, where systems are already resource-intensive and contribute significantly to global environmental challenges.

The adoption of Green AI in healthcare systems aligns with the broader objective of sustainable digital transformation. Sustainable digital transformation refers to the integration of digital technologies in a manner that supports environmental protection, economic efficiency, and social equity. In this context, Green AI plays a crucial role by enabling healthcare organizations to leverage advanced technologies while minimizing their ecological impact. For example, energy-efficient AI models, cloud optimization, and edge computing can reduce energy consumption, while telemedicine and remote monitoring can decrease the need for physical infrastructure and transportation, thereby lowering carbon emissions.

Despite its potential, the implementation of Green AI in healthcare faces several challenges, including high initial investment, lack of awareness, technical complexity, and regulatory constraints. Moreover, there is a need to ensure that the adoption of AI technologies does not exacerbate existing inequalities in healthcare access. Therefore, it is essential to develop a comprehensive framework that integrates technological, organizational, and environmental aspects to guide the sustainable adoption of AI in healthcare systems.

This study aims to review the existing literature on Green AI and propose a framework for its adoption in healthcare. By examining current trends, challenges, and opportunities, the paper contributes to a deeper understanding of how healthcare systems can achieve sustainable digital transformation through the responsible use of AI technologies.

LITERATURE REVIEW

The concept of Green Artificial Intelligence (Green AI) has emerged as a critical area of research at the intersection of sustainability and digital transformation, particularly within the healthcare sector. As healthcare systems increasingly adopt AI-driven technologies for diagnosis, treatment, and operational efficiency, concerns regarding energy consumption, environmental impact, and ethical implications have gained prominence. This literature review synthesizes existing research on Green AI, its applications in healthcare, and its role in promoting sustainable digital transformation.

1. Evolution of AI in Healthcare

Artificial Intelligence has significantly transformed healthcare by enhancing diagnostic accuracy, improving patient outcomes, and optimizing operational processes. Early studies by Eric Topol (2019) highlight the potential of AI to augment clinical decision-making and enable precision medicine. AI technologies such as machine learning, natural language processing, and computer vision are widely used in radiology, pathology, and predictive analytics. These advancements have contributed to the development of "Healthcare 4.0," characterized by interconnected systems, real-time data processing, and patient-centric care.

However, the increasing complexity of AI models, particularly deep learning algorithms, has led to substantial computational requirements. Emma Strubell et al. (2019) demonstrate that training large AI models can result in significant carbon emissions, comparable to the lifetime emissions of multiple vehicles. This has raised concerns about the environmental sustainability of AI-driven healthcare systems.

2. Concept and Principles of Green AI

The term Green AI was formally introduced by Roy Schwartz et al. (2020), emphasizing the need to prioritize computational efficiency and environmental impact alongside model performance. Green AI focuses on reducing energy consumption, optimizing algorithms, and promoting the use of sustainable computing resources. It advocates for transparency in

reporting the energy costs of AI models and encourages the development of lightweight and efficient algorithms.

In healthcare, Green AI is particularly relevant due to the sector's resource-intensive nature. Julian Karliner et al. (2019) report that healthcare contributes significantly to global greenhouse gas emissions, making it imperative to adopt sustainable technologies. Green AI aligns with this objective by minimizing the environmental footprint of digital healthcare systems.

3. APPLICATIONS OF GREEN AI IN HEALTHCARE

3.1 AI-Driven Diagnostics and Imaging

AI applications in medical imaging, such as radiology and pathology, have improved diagnostic accuracy and efficiency. However, these systems often rely on computationally intensive models. Green AI approaches focus on optimizing these models to reduce energy consumption without compromising accuracy. Techniques such as model compression, pruning, and efficient architecture design are increasingly being adopted.

3.2 Telemedicine and Remote Healthcare

Telemedicine has emerged as a sustainable healthcare solution, particularly during and after the COVID-19 pandemic. AI-powered telemedicine platforms enable remote consultations, reducing the need for physical visits and associated carbon emissions. Studies indicate that telemedicine significantly lowers transportation-related emissions and improves healthcare accessibility, especially in rural areas.

3.3 Smart Hospital Management

AI is widely used in hospital management systems to optimize resource allocation, energy consumption, and operational efficiency. Smart hospitals leverage AI to monitor energy usage, manage patient flow, and reduce waste. Green AI enhances these systems by ensuring energy-efficient operations and sustainable resource management.

3.4 Drug Discovery and Research

AI has accelerated drug discovery processes by analyzing large datasets and identifying potential drug candidates. Green AI ensures that these processes are conducted in an energy-efficient manner, reducing the environmental impact of pharmaceutical research.

4. DRIVERS OF GREEN AI ADOPTION IN HEALTHCARE

The adoption of Green AI in healthcare is driven by several factors. Environmental regulations and sustainability goals are major drivers, as governments and organizations aim to reduce carbon emissions and promote green practices. Rising energy costs associated with AI infrastructure also encourage the adoption of energy-efficient solutions. Additionally, advancements in hardware and software technologies have made it possible to develop more efficient AI models.

Corporate social responsibility (CSR) initiatives and increasing awareness of environmental issues further motivate healthcare organizations to adopt Green AI. The integration of sustainability into organizational strategies is becoming a key priority, driving the adoption of environmentally responsible technologies.

5. CHALLENGES IN IMPLEMENTING GREEN AI

The adoption of Green Artificial Intelligence (Green AI) in healthcare systems presents significant opportunities for improving sustainability; however, its implementation is accompanied by several complex challenges. These challenges span technological, financial, organizational, and ethical dimensions, making the transition toward sustainable AI-driven healthcare systems difficult.

One of the most critical challenges is high initial investment and financial constraints. The deployment of Green AI requires advanced infrastructure, including energy-efficient data centers, high-performance computing systems, and optimized hardware such as GPUs and AI-specific chips. Healthcare institutions, especially in developing economies, often operate under budget constraints and may find it difficult to justify the upfront costs of sustainable technologies, even though they offer long-term cost savings. Additionally, the cost of maintaining and upgrading these systems further adds to the financial burden.

Another major challenge is the trade-off between model performance and energy efficiency. Traditional AI systems in healthcare prioritize accuracy and predictive performance, which are crucial in clinical decision-making. Green AI, however, emphasizes reducing computational complexity and energy consumption, which may sometimes result in slightly lower accuracy. In critical healthcare applications such as disease diagnosis or treatment planning, even minimal reductions in accuracy can have serious consequences, making it difficult for organizations to adopt energy-efficient models over highly accurate but resource-intensive ones.

The lack of awareness and technical expertise is also a significant barrier. Many healthcare professionals and administrators are not fully aware of Green AI concepts or their potential benefits. Moreover, implementing Green AI requires specialized skills in both healthcare and sustainable computing, which are currently in limited supply. The absence of trained personnel can hinder the adoption and effective utilization of Green AI technologies.

Data privacy and security concerns further complicate the implementation process. AI systems rely heavily on large volumes of patient data for training and analysis. Ensuring the confidentiality, integrity, and security of sensitive health data is a major challenge, particularly with increasing cyber threats. Compliance with data protection regulations, such as GDPR and other national frameworks, adds another layer of complexity to the deployment of AI systems.

Another important challenge is the lack of standardized frameworks and regulatory guidelines for Green AI in healthcare. While there are general guidelines for AI and sustainability, there is a lack of specific policies addressing the environmental impact of AI technologies in healthcare. This creates uncertainty for organizations and slows down adoption. Policymakers and regulatory bodies need to establish clear standards and guidelines to promote sustainable AI practices.

Additionally, organizational resistance to change poses a significant challenge. Healthcare systems are often complex and hierarchical, with established workflows and practices. The introduction of new technologies may face resistance from healthcare professionals who are accustomed to traditional methods. Concerns about job displacement, increased workload, and the reliability of AI systems can further hinder adoption.

6. INTEGRATION OF GREEN AI WITH SUSTAINABLE HEALTHCARE

The integration of Green Artificial Intelligence (Green AI) with sustainable healthcare represents a transformative approach to improving healthcare delivery while minimizing environmental impact. Green AI focuses on developing energy-efficient algorithms, optimizing computational processes, and reducing the carbon footprint associated with AI systems. When aligned with the principles of sustainable healthcare—environmental responsibility, economic efficiency, and social equity—it creates a holistic framework for responsible digital transformation.

One of the key aspects of this integration is environmental sustainability. Healthcare systems are resource-intensive, consuming large amounts of energy and generating significant waste. Green AI contributes by reducing the energy requirements of data processing and storage through optimized algorithms, model compression, and the use of energy-efficient hardware. Additionally, the adoption of cloud computing powered by renewable energy and edge computing reduces data transmission and energy consumption, thereby lowering the overall carbon footprint of healthcare operations.

From an economic perspective, Green AI enhances efficiency and cost-effectiveness. By streamlining processes such as diagnostics, patient monitoring, and hospital management, AI reduces operational inefficiencies and resource wastage. Energy-efficient systems also lower electricity costs over time, making healthcare systems more financially sustainable. Furthermore, predictive analytics enabled by AI can support preventive healthcare, reducing long-term treatment costs and improving resource allocation.

The integration also promotes social sustainability by improving access to healthcare services. AI-powered telemedicine and remote monitoring systems enable healthcare delivery to underserved and rural populations, reducing geographical barriers. However, ensuring equitable access to these technologies is essential to avoid widening the digital divide.

Overall, the integration of Green AI with sustainable healthcare requires a lifecycle approach that considers the design, deployment, and maintenance of AI systems. It also necessitates strong policy support, stakeholder collaboration, and continuous monitoring. By aligning technological innovation with sustainability goals, healthcare systems can achieve improved patient outcomes, reduced environmental impact, and long-term resilience.

7. EMERGING TRENDS AND FUTURE DIRECTIONS

The literature identifies several emerging trends in Green AI and healthcare. These include the development of energy-efficient hardware, such as specialized AI chips, and the use of edge computing to reduce data transmission and energy consumption. Blockchain technology is also being explored for secure and transparent data management.

Furthermore, the concept of Healthcare 5.0 emphasizes a human-centric approach, integrating advanced technologies with a focus on sustainability and patient well-being. Future research is expected to focus on developing standardized metrics for measuring the sustainability of AI systems and exploring the long-term impact of Green AI on healthcare outcomes.

Overall, the literature highlights the growing importance of Green AI in promoting sustainable healthcare systems. While significant progress has been made in developing and implementing AI technologies, their environmental impact remains a critical concern. Green AI offers a promising solution by balancing technological innovation with sustainability goals. However, challenges related to cost, awareness, and regulatory frameworks need to be addressed to ensure widespread adoption. Future research should focus on empirical studies

and the development of comprehensive frameworks to guide sustainable AI adoption in healthcare.

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