

Green AI and Environmental Sustainability

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Abstract

Artificial Intelligence (AI) has emerged as one of the most transformative technologies of the twenty-first century, with applications in healthcare, finance, education, transportation, agriculture, energy and environmental management. However, the rapid development of increasingly large and computationally intensive AI models has created significant environmental concerns, including high electricity consumption, carbon emissions, water consumption, electronic waste and demand for energy-intensive computing infrastructure. Green Artificial Intelligence (Green AI) has therefore emerged as an important approach towards reducing the environmental footprint of AI while maintaining useful levels of performance. Green AI focuses on developing energy-efficient algorithms, optimising models and hardware, reducing computational requirements, using renewable energy and improving the sustainability of data centres. At the same time, AI can contribute to environmental sustainability by supporting renewable energy forecasting, climate modelling, biodiversity monitoring, smart agriculture and efficient resource

management. This paper presents a conceptual study of Green AI and examines its relationship with environmental sustainability through a review of existing literature. The study adopts a descriptive and conceptual research methodology based on secondary sources, including academic journal articles, research papers and reports from international organisations. The findings indicate that Green AI requires consideration of the entire AI lifecycle, from data collection and model training to deployment, infrastructure and disposal of hardware. The study recommends greater energy-efficiency measurement, transparent environmental reporting, renewable-energy integration, efficient model design and stronger collaboration between technology companies, researchers and policymakers.

Keywords: Green AI, Artificial Intelligence, Environmental Sustainability, Energy Efficiency, Carbon Emissions, Sustainable Computing, Renewable Energy, Green Computing.

I.INTRODUCTION

Artificial Intelligence has become an important component of modern digital transformation. Machine learning and deep learning systems are increasingly being used to analyse large datasets, automate decision-making and improve efficiency across different sectors. AI has also created new opportunities for addressing environmental challenges through climate forecasting, renewable-energy management, biodiversity conservation and intelligent resource allocation. However, the environmental cost of AI is becoming an important area of concern. The development and operation of sophisticated AI models require considerable computational resources. Training and deploying AI systems generally depend on data centres containing servers, specialised processors and cooling infrastructure. As AI models become larger and their use increases, electricity demand and associated environmental impacts can also increase. The International Energy Agency reported that global data-centre electricity consumption was approximately 415 TWh in 2024, representing around 1.5% of global electricity consumption. Its 2025 base-case projection estimated that data-centre electricity consumption could reach approximately 945 TWh by 2030, with AI being an important driver of this growth. These developments have led to growing interest in Green AI. Schwartz et al. introduced Green AI as an approach that treats computational efficiency and the environmental cost of AI as important considerations alongside conventional measures such as accuracy. Green AI therefore seeks to answer two related questions: How can AI systems become environmentally sustainable? and How can AI itself be used to support environmental sustainability?

CONCEPTUAL STUDY

Green AI can be understood as the development and application of artificial intelligence in ways that minimise environmental impacts while maintaining appropriate performance.

The concept can broadly be divided into two dimensions:

Green-in AI

Green-in AI refers to making the development and operation of AI systems themselves more environmentally efficient. It focuses on reducing:

- Electricity consumption
- Computational requirements
- Carbon emissions
- Water consumption associated with cooling
- Hardware requirements
- Electronic waste
- Computational cost

Techniques such as model compression, pruning, quantisation, efficient neural-network architectures, early stopping and efficient hardware can contribute to this objective.

Green-by AI

Green-by AI refers to using AI technologies to address environmental and sustainability problems. Examples include:

- Predicting renewable-energy generation
- Optimising electricity grids
- Monitoring deforestation
- Predicting extreme weather
- Improving agricultural productivity
- Monitoring biodiversity
- Reducing industrial energy consumption
- Optimising transportation routes
- Managing water resources

Recent literature therefore treats Green AI not simply as reducing the energy used by AI, but as a broader approach involving both environmentally efficient AI and AI-enabled environmental solutions.

AI Lifecycle and Environmental Sustainability

The environmental impact of AI does not occur only during model training. It can occur throughout the AI lifecycle:

Data collection → Data processing → Model development → Training → Deployment → Inference → Hardware production → Hardware disposal

The United Nations Environment Programme identifies energy, water, minerals, emissions and electronic waste among the environmental impacts that can arise across the AI lifecycle. Therefore, environmental sustainability should be considered from the beginning of an AI project rather than only after the model has been developed.

Literature Review

Schwartz et al. (2020) introduced the Green AI perspective and argued that efficiency should be considered alongside accuracy when evaluating AI research. They proposed reporting the computational and financial “price tag” of AI systems so that researchers can compare efficiency as well as performance. This work established an important foundation for environmentally conscious AI research. Verdecchia et al. (2023) conducted a systematic review of Green AI research and analysed 98 primary studies. Their review identified major research areas including monitoring the environmental footprint of AI models, improving hyperparameter selection and benchmarking models according to sustainability-related criteria. The review also observed that much of the research had focused on training and laboratory experiments, highlighting the need to transfer research findings into industrial practice. Bolón-Canedo et al. (2024) examined Green AI as an approach for developing energy-efficient machine-learning systems. Their review discusses both Green-in AI and Green-by AI and identifies algorithmic optimisation, efficient hardware, energy measurement and sustainable practices as important areas. Chowdhury et al. (2024) proposed a comprehensive framework for Green AI that includes model optimisation, efficient algorithms, energy-efficient hardware and sustainable data-centre management. The study highlights the importance of considering both technological and infrastructural factors in reducing AI's environmental footprint. The United Nations Environment Programme (2024) emphasised that the environmental consequences of AI should be examined across its complete lifecycle. Its analysis includes energy, water, mineral consumption, emissions and electronic waste and calls for improved measurement and reporting frameworks. The International Energy Agency (2025) examined the relationship between AI and energy demand. It found that data-centre electricity consumption is expected to increase substantially during the present decade, while also identifying opportunities for AI to improve energy-system efficiency and support clean-energy technologies. Recent research further indicates that AI has a sustainability paradox: AI can simultaneously create environmental pressures through energy, water, materials and infrastructure requirements while helping other sectors reduce environmental impacts.

Thus, the literature demonstrates that Green AI should be approached from both sides: reducing the environmental cost of AI and increasing AI's contribution to environmental sustainability.

Research Objectives

The major objectives of this study are:

- To understand the concept and significance of Green AI.
- To examine the relationship between Artificial Intelligence and environmental sustainability.
- To identify the major environmental impacts associated with AI systems.
- To examine techniques for reducing the energy and carbon footprint of AI.
- To understand how AI can contribute to solving environmental problems.
- To identify major challenges in implementing Green AI.
- To provide recommendations for promoting sustainable AI development.

Research Methodology

This study follows a **descriptive and conceptual research methodology**.

The research is based entirely on **secondary data** collected from academic journal articles, research publications, institutional reports and credible online research databases.

The major sources consulted include:

- Academic journal articles on Green AI
- Systematic literature reviews
- Research papers on sustainable Artificial Intelligence
- International Energy Agency reports
- United Nations Environment Programme publications
- Scholarly publications relating to sustainable computing and data centres

The literature was examined thematically under the following areas:

Green AI → Energy Efficiency → Carbon Reduction → Sustainable Infrastructure → Green-by AI → Environmental Applications → Challenges → Recommendation

Major Concepts of Green Ai

Energy-Efficient Algorithms

AI models can be designed to achieve required performance using fewer computational resources. Efficient algorithms can reduce processing time and electricity consumption.

Model Compression

Large AI models can sometimes be compressed through techniques such as:

- Pruning
- Quantisation
- Knowledge distillation
- Parameter sharing
- These approaches can reduce model size and computational requirements.

Efficient Hardware

Specialised processors such as GPUs, TPUs and other AI accelerators can improve computational efficiency. The objective is to obtain greater performance for each unit of electricity consumed.

Renewable Energy

Data centres can reduce their carbon intensity by using electricity from renewable sources such as solar, wind and hydropower. The IEA projects that renewables will provide a substantial share of the additional electricity required by data centres through 2030.

Sustainable Data Centres

- Data centres can improve environmental performance through:
- Efficient cooling systems
- Improved power usage effectiveness
- Renewable electricity
- Efficient server utilisation
- Heat-management systems
- Strategic geographical location

Carbon-Aware Computing

AI workloads can be scheduled according to periods or locations where electricity has a lower carbon intensity. This can reduce emissions without necessarily reducing computational output.

Green-by AI Applications

AI can support environmental sustainability through:

Climate prediction → Renewable energy → Smart agriculture → Biodiversity → Water management → Waste management → Smart transportation

These applications demonstrate that AI can become both an environmental challenge and an environmental solution.

Findings

The conceptual analysis and literature review produced the following major findings.

AI has a significant and growing resource requirement

AI development requires computational infrastructure, electricity and cooling. The increasing deployment of AI-enabled data centres is therefore an important sustainability issue.

Environmental impact extends beyond electricity

The environmental footprint of AI includes not only electricity consumption but also water, minerals, hardware manufacturing, carbon emissions and electronic waste. UNEP's lifecycle approach highlights the importance of considering these factors together.

Model efficiency is an important component of Green AI

Smaller and computationally efficient models can reduce energy requirements. Techniques such as quantisation, pruning and efficient architecture design can contribute to this objective.

Renewable energy can reduce carbon intensity

The environmental impact of electricity consumption depends partly on the source of electricity. Integrating renewable energy into AI infrastructure can therefore reduce associated carbon emissions.

AI can contribute to environmental sustainability

AI can improve renewable-energy forecasting, environmental monitoring, agriculture, transportation and resource management. Consequently, the environmental effect of AI cannot be evaluated only by examining its electricity consumption.

Measuring environmental performance is essential

Traditional AI evaluation often emphasises accuracy, speed and cost. Green AI requires additional indicators such as energy consumption, carbon emissions, water usage and computational requirements.

There is no single solution

Green AI requires action at several levels:

Algorithm + Model + Hardware + Data Centre + Energy Source + Lifecycle Management + Policy

Therefore, improving only one component may not be sufficient to achieve overall environmental sustainability.

Recommendations

Based on the literature reviewed, the following recommendations are proposed:

❖ Include sustainability metrics in AI development

Researchers and organisations should measure energy consumption, carbon emissions and computational requirements in addition to accuracy and performance.

❖ Encourage smaller and efficient models

Developers should select the smallest model capable of achieving the required task rather than automatically using the largest available model.

❖ Promote renewable-powered AI infrastructure

Technology companies and data-centre operators should increase the use of renewable electricity and explore energy-storage solutions.

❖ **Improve environmental reporting**

AI companies should provide greater transparency regarding the energy and environmental footprint of model training and deployment.

❖ **Adopt lifecycle assessment**

Environmental assessment should cover data collection, model development, training, inference, hardware manufacturing, infrastructure and disposal.

❖ **Promote sustainable hardware**

Longer hardware lifetimes, repairability, recycling and responsible sourcing of minerals should be incorporated into AI infrastructure planning.

❖ **Encourage Green-by AI applications**

Investment should also focus on applications where AI can support environmental objectives, such as renewable-energy optimisation, climate monitoring, smart agriculture and biodiversity conservation.

❖ **Develop common standards**

Governments, technology companies and academic institutions should collaborate to establish standardised methods for reporting AI energy consumption, carbon emissions and other environmental impacts.

II.CONCLUSION

Green AI represents an important approach to making Artificial Intelligence compatible with long-term environmental sustainability. The rapid growth of AI has created substantial opportunities for economic and technological development, but it has also increased concerns regarding electricity consumption, carbon emissions, water use, hardware demand and electronic waste. The literature shows that Green AI has two complementary dimensions. Green-in AI focuses on reducing the environmental footprint of AI through efficient algorithms, model optimisation, efficient hardware, renewable energy and sustainable data-centre practices. Green-by AI focuses on using AI to address environmental challenges such as climate change, renewable-energy management, biodiversity conservation, agriculture and resource efficiency. The future development of AI should therefore not be measured only by how accurate or powerful an AI model is. Environmental efficiency should also become an important criterion. A sustainable AI ecosystem requires cooperation among researchers, technology companies, governments and users.

Ultimately, Green AI does not mean preventing technological progress. Instead, it means designing and using AI in a manner that achieves useful technological outcomes while reducing unnecessary environmental costs. Integrating sustainability into the entire AI lifecycle can help ensure that the future growth of Artificial Intelligence contributes positively to both technological development and environmental protection.

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