IRJEMS International Research Journal of Economics and Management Studies
Published by Eternal Scientific Publications
ISSN: 2583 – 5238 / Volume 4 Issue 12 December 2025 / Pg. No: 174-178
Paper Id: IRJEMS-V4I12P121, Doi: 10.56472/25835238/IRJEMS-V4I12P121

Original Article

Sustainability and Green AI in Semiconductor and Telecom Industries

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Received Date: 28 November 2025 Revised Date: 20 December 2025 Accepted Date: 27 December 2025 Published Date: 30 December 2025

Abstract: *The high-speed development of the artificial intelligence (AI) technologies has aggravated energy consumption and environmental effects in semiconductor manufacturing and telecommunication networks significantly. To make these sectors sustainable, the implementation of green AI and eco friendly manufacturing algorithms, energy optimization algorithms and hardware and network infrastructure circular economy versions should be integrated. This paper reviews existing practices and strategies to reduce environmental footprints which include energy efficient semiconductor fabrication, AI-controlled network energy management and the sustainability of lifecycle through the use of circular economy strategies. The most notable insights include the fact that AI and sustainable design principles can be used together to achieve a significant reduction in carbon emissions, maximized energy use, and a more responsible approach towards electronic waste management. The work also identifies the emerging challenges such as the trade-offs between computational performance and energy efficiency and provides future research and industry adoption fields. The strategies are essential in the implementation of sustainable technological advancement and the preservation of performance and reliability of AI-driven systems.*

Keywords: *Green AI, Sustainable Semiconductor Manufacturing, Energy Optimization, Circular Economy, AI Hardware, Telecom Networks, Eco-friendly Manufacturing.*

I. INTRODUCTION

The semiconductor and telecommunications sectors constitute the foundation of the modern information technology which facilitates the artificial intelligence, cloud computing and faster communication networks. The environmental impacts of these industries have however increased significantly. The production of semiconductors requires energy-intensive manufacturing, the use of large amounts of chemicals and substantial amounts of water [1] and telecommunication networks require large amounts of electricity to provide base stations, data centers and edge computing infrastructure [2]. As AI is fast becoming used in network management, data analysis, and autonomous systems, an increase in energy demand may be assumed.

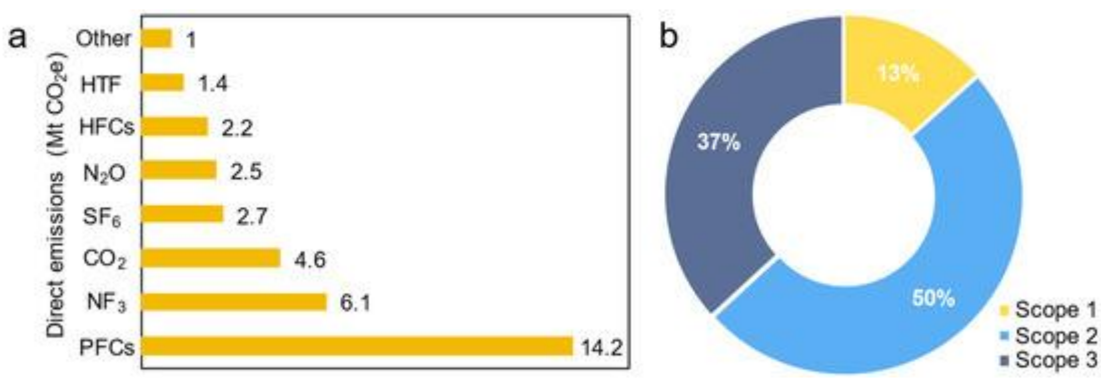

Figure 1. (a) Different Pollutants from the Direct Emissions of Semiconductor Manufacturing in 2021; (B) The Proportion of Scope 1, Scope 2, and Scope 3 GHG Emissions from Semiconductor Manufacturing Companies in Taiwan In 2020.

Green AI is a concept that focuses on minimizing the amount of energy used and environmental footprints of AI systems without compromising its computational performance [3]. Green AI is the design of algorithms and manufacturing of hardware and deployment of networks in a sustainable manner. These are environmentally friendly semiconductor manufacturing, energy optimization algorithms in telecom networks, and hardware reuse and recycling models of a circular economy [4].

The paper examines the present-day approaches to sustainable AI implementation in the semiconductors and telecom sectors. It assesses manufacturing gains, algorithmic optimization and lifecycle management strategies. There are also illustrative figures and tables that provide a summary of energy consumption levels, process efficiencies and the adoption of the circular economy. Through a combination of research work by various fields, the work offers a holistic model of integrating sustainability and AI within these sectors that are of high importance.

II. SUSTAINABILITY CHALLENGES IN SEMICONDUCTOR AND TELECOM INDUSTRIES

A) Environmental Impacts of Semiconductor Manufacturing

Semiconductor production demands the presence of clean rooms, accurate temperature, and chemical etching which are highly energy and water consuming activities [5]. It has been estimated globally that one semiconductor fab can use 10-20 MW of power which generates a lot of greenhouse gas (GHG) emissions [6]. Moreover, photolithography and chemical deposition procedures also add to the chemical waste and air pollution [7]. Table 1 is a summary of major environmental effects at various semiconductor manufacturing phases.

Table 1: Environmental Impacts of Semiconductor Manufacturing [5], [6]

Process Stage	Energy Use (kWh/unit)	Water Use (L/unit)	GHG Emissions (kg CO_2e/unit)
Wafer Fabrication	500–700	3,000–5,000	200–300
Photolithography	100–150	200–500	50–70
Chemical Etching	50–80	100–200	20–40
Packaging and Testing	30–60	50–100	10–25

B) Energy Consumption in Telecom Networks

Telecom infrastructure comprises base stations, core network nodes and data centers. Base stations consume 50-60 percent of the energy used in mobile networks, much of which is necessary to keep the base station operational at all times and to process signals [8]. Telecom-based services utilize data centers that consume a lot of energy, and network optimization based on AI could raise the number of computational loads [9].

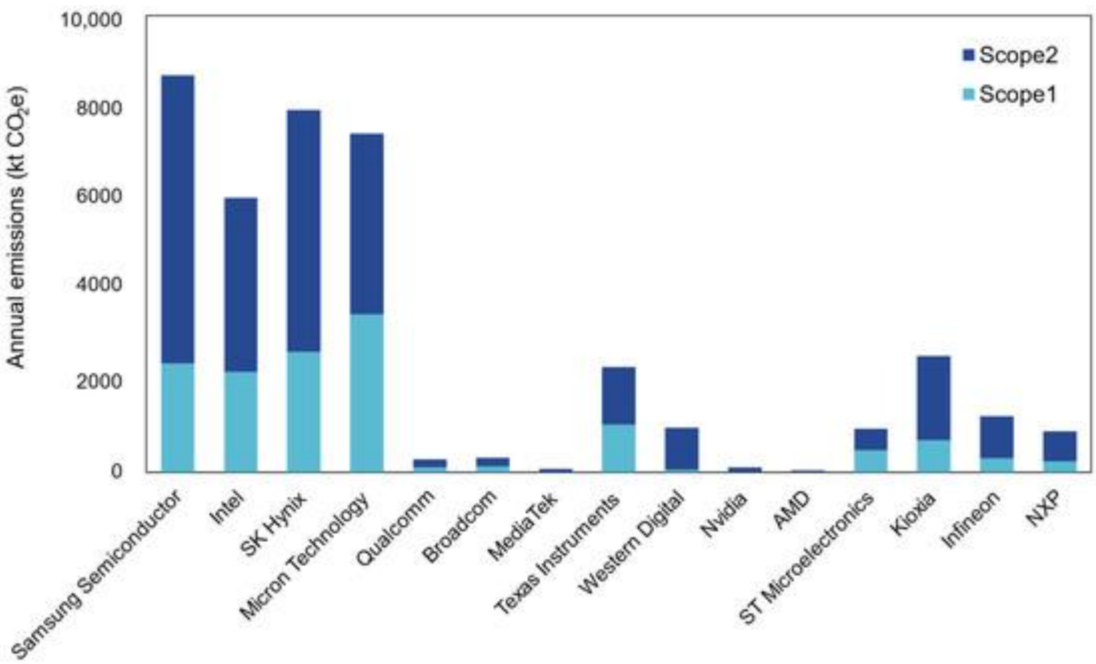

Figure 2. Scope 1 And Scope 2 Emissions of the 15 Main Semiconductor Market Entities In 2021.

The process of decreasing the energy consumption in telecommunication networks involves the application of AI-based optimization algorithms, such as resource allocation dynamically, traffic forecasting, and base stations sleeping-mode management [10].

III. GREEN AI PRINCIPLES

Green AI is designed to strike a compromise between the computational performance and the environmental sustainability. Key principles include:

1. Energy-Efficient Algorithms Design - The development of AI models that can be as accurate and consume less computation [3].
2. Hardware-Aware Training - Neural network architectures that are energy efficient [11].
3. Lifecycle Sustainability - Incorporating eco-design, recycling and circular economy [12].

Combining these principles permits AI to be implemented without inequitably contributing to the heightened environmental influence, which is consistent with the sustainability objectives of technological advancement.Greener Semiconductor production.

IV. ECO-FRIENDLY SEMICONDUCTOR MANUFACTURING

A) Process Optimization

The lithography, etching, and deposition processes can be optimised in order to achieve energy efficiency in the semiconductor fabrication. Techniques include:

- Low-Temperature Processing: Minimizes the use of energy to treat wafers [13].
- Chemical Reuse and Recycling: Reduces the hazardous waste and water usage [14].
- Automation and AI Monitoring: AI controls process parameters to maximize energy consumption and differences [15].

B) Green Materials

Replacing conventional materials with environmentally friendly (e.g. lead-free solders, biodegradable chemicals) alleviates environmental hazards [16].

V. AI-ENABLED ENERGY OPTIMIZATION IN TELECOM NETWORKS

A) Base Station Energy Management

AI is capable of dynamically controlling power consumption of base stations according to the real-time traffic and environmental conditions [17]. Techniques include:

- Sleep Mode Algorithms: Discontinue unutilized equipment temporarily [18].
- Load Prediction Models: Predict network traffic in order to optimize energy allocation [19].

B) Data Center Optimization

The workload scheduling, cooling optimization, and predictive maintenance are examples of AI-based techniques that assist in reducing energy consumption in data centers of telecom companies [20], [21]. Table 2 presents energy savings of AI-based optimizations.

Table 2: AI-Based Energy Savings in Telecom Data Centers [20], [21]

Technique	Energy Savings (%)
Predictive Cooling	15–20
Dynamic Workload Scheduling	10–15
Server Consolidation	5–10

VI. CIRCULAR ECONOMY MODELS FOR HARDWARE AND NETWORKS

A) Hardware Recycling

The concepts of the circular economy focus on the reuse, refurbishment, and recycling of electronic components [22]. To minimize the electronic waste and reclaim useful materials, semiconductor and telecom companies use take-back programs [23].

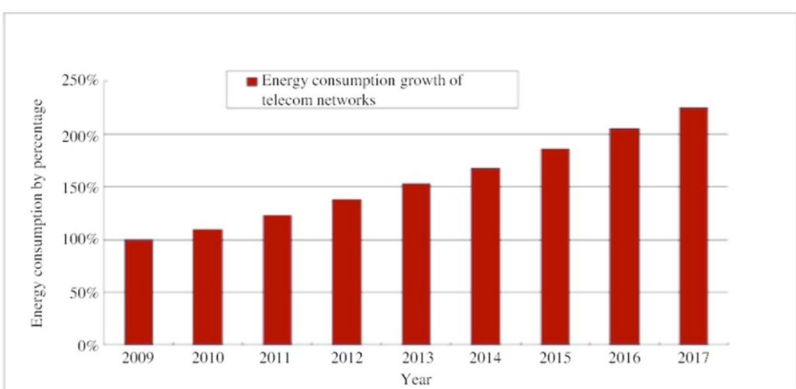

Figure 3. Energy Consumption Forecast of Telecom Networks [55].

B) Life Cycle Assessment

Lifecycle assessment (LCA) considers the effects of production to disposal. LCA measures are used to make sustainable product design and supply chain decisions [24].

VII. ALGORITHMIC STRATEGIES FOR GREEN AI

The algorithmic methods towards energy efficiency are:

1. Model Compression: Task The neural network is compressed in size without compromising performance [25].
2. Quantization: Representation of high efficiency computations into lower level formats [26].
3. Pruning: This method eliminates superfluous connections in a neural network [27].

These technologies decrease the amount of energy used and the carbon footprint without necessitating serious impacts on the performance of AI.

VIII. CASE STUDIES AND INDUSTRY IMPLEMENTATIONS

A) Semiconductor Industry

Intel and TSMC have also introduced designs of fab that are energy efficient, water reuse programs, and minimization of chemical wastes [28], [29].

B) Telecom Industry

Vodafone, China Mobile and AT&T have implemented AI-based energy management, base station sleep and data center optimizations [30], [31]. These case studies show quantifiable GHG emission and energy savings.

IX. FUTURE TRENDS AND RESEARCH DIRECTIONS

Areas of future research are:

1. Smart Manufacturing AI: A predictive maintenance and process efficiency AI using IoT sensors [32].
2. Sustainable AI Hardware: The Creation of low-power AI workload computer chips [33].
3. Network Level Ai Optimization: Multi-layer energy control of 5G/6G networks [34].
4. Policy and Regulatory Support: Rewarding the implementation of a circular economy and reduction of emissions [35].

X. CONCLUSION

Sustainability and Green AI in semiconductor and telecom industries are essential for reducing environmental impact while meeting the increasing computational demands of AI. This paper reviewed strategies including eco-friendly manufacturing, AI-driven energy optimization, and circular economy adoption. Integration of these approaches can significantly reduce GHG emissions, optimize energy use, and Green AI and sustainability in semiconductor and telecom industries are critical towards counteracting the negative environmental effects whilst addressing the rising AI computational needs. The paper considered such strategies as the environmentally friendly production, artificial intelligence based energy optimization, and the implementation of the circular economy. These strategies can be used to minimize GHG emissions, optimize energy use and improve lifecycle sustainability through integration. Further research, cooperation with the industry, and governmental assistance are crucial to developing sustainable growth in AI-powered technologies.enhance lifecycle sustainability. Continued research, industry collaboration, and regulatory support are vital for achieving sustainable growth in AI-enabled technologies.

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