Published by :
https://www.ijert.org/
An International Peer-Reviewed Journal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14, Issue 02, NCRTCS - 2026

A Green Cloud Computing Perspective Cost-Efficient and Eco-Friendly Cloud Computing Solutions

AI-Driven Cost Optimization and Energy-Efficient Strategies for Green Cloud Computing

Chetana Popat Sapate.
Msc computer science
Dr.D.Y.Patil ACS College Pmpri 411018
Pune, India

Pachi Pamdurang Salunkhe.
Msc computer science
Dr.D.Y.Patil ACS College Pimpri 411018
Pune,India

Abstract **- The rapid adoption of cloud computing has significantly transformed modern information technology infrastructure by offering scalability, flexibility, and cost advantages. However, the exponential growth of cloud services has also resulted in increased energy consumption, rising operational costs, and adverse environmental impacts due to carbon emissions from large-scale data centers. Green cloud computing has emerged as a sustainable approach to address these challenges by integrating energy-efficient technologies and eco-friendly practices. This paper presents an analytical study of cost optimization and energy-efficient strategies in green cloud computing, with a particular focus on AI-driven resource management. The study examines key green cloud techniques such as virtualization, dynamic resource allocation, renewable energy integration, and intelligent workload scheduling. A comparative evaluation is conducted to analyze cost–energy trade-offs between traditional cloud systems and green cloud models. The findings indicate that AI-enabled green cloud strategies significantly reduce energy consumption and long-term operational costs while maintaining acceptable performance levels.**

Keywords - Green Cloud Computing, Cost Optimization, Energy Efficiency, AI-Driven Resource Management, Sustainable Cloud Infrastructure, Carbon Emission Reduction

INTRODUCTION

Cloud computing has become a foundational technology for organizations across industries, enabling on-demand access to computing resources, data storage, and applications. Its ability to provide scalability and cost efficiency has led to widespread adoption by enterprises, governments, and educational institutions. Despite these advantages, the increasing reliance on cloud services has raised serious concerns regarding energy consumption and environmental sustainability. Large-scale cloud data centers consume enormous amounts of electricity, contributing significantly to carbon emissions and operational expenses.

Traditional cloud infrastructures are primarily powered by non-renewable energy sources and often operate with inefficient resource utilization, leading to energy wastage. As global awareness of climate change and sustainable development grows, there is increasing pressure on cloud service providers to adopt environmentally responsible computing practices. In this context, green cloud computing has emerged as a promising paradigm aimed at reducing energy usage, minimizing carbon footprints, and optimizing operational costs.

Recent advancements in artificial intelligence (AI) and machine learning have further enhanced the potential of green cloud computing. AI-driven techniques enable intelligent workload scheduling, predictive resource allocation, and energy-aware decision-making, allowing cloud systems to operate more efficiently. However, implementing green cloud solutions involves trade-offs between cost, performance, scalability, and sustainability. Understanding these trade-offs is crucial for enterprises and cloud providers seeking to balance economic and environmental objectives.

This paper aims to analyze AI-driven cost optimization and energy-efficient strategies in green cloud computing. By examining existing techniques and comparing traditional and green cloud approaches, the study provides insights into how sustainable cloud infrastructures can be designed without compromising performance

II. RELATED WORK AND RESEARCH GAP

Several studies have explored energy-efficient approaches in cloud computing. Virtualization and server consolidation techniques have been widely recognized for reducing the number of active physical servers, thereby lowering power consumption. Other research has focused on energy-aware scheduling algorithms that dynamically allocate resources based on workload demand. The integration of renewable energy sources such as solar and wind power has also been proposed to reduce reliance on fossil fuels.

Recent literature highlights the growing role of AI in optimizing cloud operations. AI-based workload prediction and intelligent scheduling have demonstrated potential in

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reducing energy waste and improving system efficiency. However, many existing studies focus primarily on energy reduction while giving limited attention to cost optimization and managerial decision-making aspects.

Despite extensive research on green cloud technologies, a significant gap exists in developing integrated frameworks that simultaneously address cost efficiency, energy optimization, and performance trade-offs using AI-driven decision models. This study addresses this gap by providing a comparative and analytical perspective on cost–energy optimization in green cloud computing.

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III. RESEARCH METHODOLOGY

This research adopts an analytical and comparative methodology to evaluate cost-efficient and energy-efficient strategies in green cloud computing.

II. . Research Type

The study is descriptive and analytical in nature, focusing on comparative evaluation and conceptual framework analysis.

III. . Data Sources

The analysis is based on secondary data collected from scholarly research articles, conference proceedings, industry reports from cloud service providers, and sustainability documentation published by major cloud platforms.

IV. . Evaluation Parameters

The strategies are evaluated based on energy consumption, operational cost, carbon footprint, scalability, and performance impact.

V. . Analytical Approach

A comparative assessment is conducted between traditional cloud systems and AI-enabled green cloud strategies to identify cost–energy trade-offs and optimization opportunities..

IV. AI-DRIVEN GREEN CLOUD OPTIMIZATION FRAMEWORK

AI-driven green cloud computing leverages intelligent algorithms to optimize resource allocation and energy usage. The proposed framework consists of four key components:

1. **Workload Monitoring Layer:**
   Continuously monitors workload patterns, resource utilization, and energy consumption.

2. **AI Decision Engine:**
   Uses machine learning algorithms to predict workload demand and optimize resource scheduling.

3. **Energy-Aware Resource Allocation:**
   Dynamically allocates virtual machines and computing resources to minimize energy usage and cost.

4. **Sustainability Management Layer:**
   Integrates renewable energy sources and monitors carbon emissions to ensure eco-friendly operations.

This framework enables proactive decision-making, reducing unnecessary resource usage while maintaining service quality.

V. COMPARATIVE EVALUATION OF GREEN CLOUD STRATEGIES

Traditional cloud computing exhibits low energy efficiency and high operational cost. Virtualization-based cloud systems show moderate improvement in both energy efficiency and cost impact. Renewable-powered cloud infrastructures demonstrate high sustainability and energy efficiency but involve moderate costs. AI-driven green cloud solutions provide very high energy efficiency and sustainability with lower long-term cost impact despite higher initial investment.

A

VI. COMPARATIVE ANALYSIS

B

Strategy	Energy Efficiency	Cost Impact	Sustainability
Traditional Cloud	Low	High	Low
Virtualized Cloud	Medium	Medium	Medium
Renewable Cloud	High	Medium	High
AI-Driven Green Cloud	Very High	Low (long-term)	Very High

C

The analysis shows that AI-driven green cloud computing provides better performance in terms of energy efficiency and long-term cost savings compared to traditional cloud systems.

D

VII. COST–ENERGY TRADE-OFF ANALYSIS

Green cloud strategies often involve higher upfront costs due to advanced infrastructure, AI implementation, and renewable energy integration. However, these investments result in reduced energy consumption, lower operational expenses, and long-term financial benefits. AI-driven optimization enables dynamic scaling, preventing over-provisioning and reducing wasteful energy usage. While slight performance trade-offs may occur during optimization phases, the overall benefits outweigh the limitations.

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VIII. CHALLENGES AND LIMITATIONS

Despite its advantages, green cloud computing faces several challenges such as high initial investment costs, technical complexity of AI-based systems, limited availability of renewable energy in certain regions, regulatory and compliance constraints, and performance trade-offs during optimization.

IX. MANAGERIAL AND PRACTICAL IMPLICATIONS

For cloud service providers, adopting AI-driven green cloud solutions can enhance operational efficiency and corporate sustainability. Enterprises can benefit from reduced long-term costs and improved environmental compliance. Policymakers can encourage adoption through incentives and sustainability regulations.

X. CONCLUSION

This paper analyzed AI-driven cost optimization and energy-efficient strategies in green cloud computing. The study demonstrated that integrating AI-based resource management with sustainable computing practices significantly reduces energy consumption and operational costs while supporting environmental sustainability. Although challenges such as high initial investment and technical complexity exist, AI-enabled green cloud computing presents a viable path toward building sustainable and future-ready cloud infrastructures. Future research may focus on experimental validation and real-world deployment of AI-driven green cloud models.

ACKNOWLEDGMENT

The author(s) would like to express sincere gratitude to all researchers and authors whose scholarly works on green cloud computing, energy-efficient systems, and AI-driven resource management have provided the theoretical foundation for this study. Special acknowledgment is given to the contributions of cloud computing pioneers and sustainability researchers whose published literature greatly supported the analysis presented in this paper.

The author(s) also acknowledge the valuable information and sustainability initiatives published by major cloud service providers such as Google Cloud and Amazon Web Services, which served as important reference sources for understanding practical green cloud implementations. Furthermore, the author(s) are thankful to the academic community for making research articles and technical resources available, enabling the successful completion of this work.

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