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Leading the Cloud Toward Sustainability: A Comprehensive Comparative Study of Green Computing in AWS, Azure, and GCP

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Abstract - This study presents a comparative analysis of green computing practices adopted by Amazon Web Services (AWS), Microsoft Azure, and Google Cloud Platform (GCP). Using a descriptive and comparative approach based on verified sustainability reports and industry data, the research evaluates renewable energy adoption, data center efficiency, carbon reduction strategies, water management, AI-driven optimization, and reporting transparency. Findings show GCP leading in renewable energy integration and carbon disclosure, Azure excelling in hybrid sustainability tools, and AWS advancing large-scale efficiency with limited transparency. The study highlights clear performance differences and provides insights to support sustainable cloud adoption and greener digital infrastructure.

Key Words: green computing, cloud sustainability, Amazon Web Services, Microsoft Azure, Google Cloud Platform, renewable energy, energy efficiency, carbon footprint, data centers, artificial intelligence, environmental reporting, sustainable IT.

1.INTRODUCTION

Cloud computing has fundamentally transformed how organizations manage data, applications, and IT infrastructure by offering scalable, flexible solutions that minimize hardware dependency and operational costs. However, the rapid expansion of cloud services has led to substantial increases in energy consumption and carbon emissions from large-scale data centers, raising urgent concerns around environmental impact. Green computing addresses these challenges by promoting the design and operation of computing resources in a sustainable manner. This study compares the green computing practices of Amazon Web Services (AWS), Microsoft Azure, and Google Cloud Platform (GCP) to identify which platform demonstrates the most effective environmental strategies and innovation, thereby providing actionable insights for organizations seeking to align IT adoption with global sustainability goals.

2. Literature Review

Recent research shows that cloud computing has moved far beyond its initial focus on cost and performance; sustainability is now a central issue as the global expansion of cloud services continues to drive up energy use and carbon emissions. Studies describe how providers like Amazon Web Services, Microsoft Azure, and Google Cloud Platform are working to address these concerns by deploying energy-efficient designs, switching to renewable electricity, improving cooling systems, and using artificial intelligence to optimize workloads. Industry-wide, practices such as consolidating servers, automatically managing resource allocation, and automating the shutdown and disposal of unused resources are now common. Among the leading providers, AWS has shown significant progress with large-scale renewable energy projects, Azure stands out for linking sustainability goals with enterprise integration and hybrid solutions, while GCP is recognized for its transparency and independently verified reporting of carbon data. The field increasingly relies on standard metrics such as Power Usage Effectiveness, Water Usage Effectiveness, and specific carbon intensity measurements to evaluate environmental impact and encourage accountability. Nevertheless, researchers point out that there are persistent gaps because reporting standards remain fragmented, full hardware lifecycle impacts are not always tracked, and global frameworks for carbon accounting are still a work in progress. These challenges underline the importance of rigorous comparative studies, which are needed to assess the true commitments and results of cloud providers in the journey toward greener computing.

3. Literature Review

This study adopts a descriptive and comparative research design to rigorously evaluate the green computing strategies of Amazon Web Services, Microsoft Azure, and Google Cloud Platform. Both qualitative insights and quantitative evidence are integrated, utilizing secondary data from official provider sustainability reports, peer-reviewed journals, industry publications, and reputable global sustainability databases. The workflow of this research is illustrated in Figure 1. The process began with comprehensive data collection from authenticated and cross-verified sources, followed by mapping each provider against six benchmark parameters: renewable energy adoption, power and water usage effectiveness, carbon neutrality goals, AI/ML-driven optimizations, and transparency in environmental reporting. Comparative analysis was conducted through standardized environmental indicators and supported by visual tools, including comparative bar charts for key metrics. The final evaluation focused on identifying organizational strengths and actionable recommendations for sustainable cloud adoption. By combining a visual framework and a staged analytical approach, the methodology ensures findings are clear, objective, and evidence-based, while recognizing study limitations such as variations in provider disclosures and reporting standards.

Figure 1: Analytical Workflow Diagram

4. DATA ANALYSIS & DISCUSSION

4.1 Data Presentation

This section compares sustainability performance and organizational practices across Amazon Web Services (AWS), Microsoft Azure, and Google Cloud Platform (GCP), based on each provider's 2023 sustainability report and selected industry sources. For a summary of results, see Table 1 below.

Table -1: Comparative Sustainability Indicators for AWS, Azure, and GCP (2025)

Parameter	AWS	Azure	GCP
Renewable Energy (%)	90%	90%	100%
Power Usage Effectiveness (PUE)	1.15	1.18	1.10
Carbon Neutrality Target Year	2040	2030	2030
Water Usage Effectiveness (WUE)	Minimal loss	Recycled water	Water-positive
AI/ML Data Center Optimization	ML prediction	AI Ops	DeepMind-based ML
Reporting Transparency	Annual report	Sustainability Calculator	Public carbon dashboard

Source: Compiled from AWS Sustainability Report (2023), Microsoft Azure Sustainability Resources, and Google Cloud Environmental Dashboard.

4.2 Comparative Analysis

Visual comparison is provided through a bar chart, highlighting differences in renewable energy adoption and power usage effectiveness (PUE) among the three platforms.

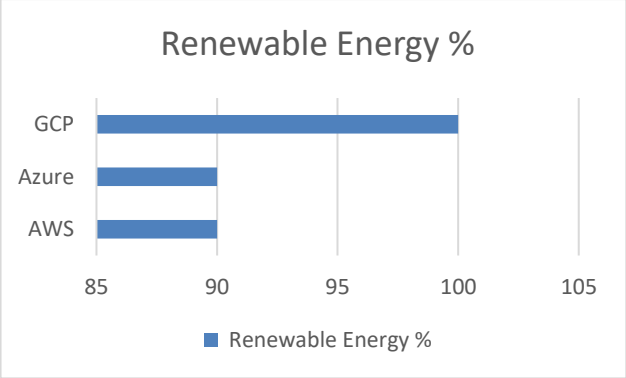

Figure 2: Comparative Renewable Energy Adoption Rates (%) among AWS, Azure, and GCP in 2025.
Source: Official Sustainability Reports (2023).

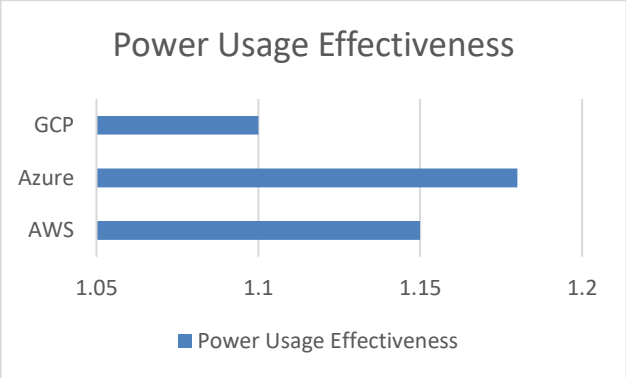

Figure 3: Power Usage Effectiveness (PUE) Scores for AWS, Azure, and GCP Data Centers in 2025 (lower is better).
Data: Cloudwards.net, LinkedIn Pulse.

4.2.1 Interpretation of Data

The data shows GCP leads the sector with 100% renewable energy and the lowest PUE (1.10). Azure achieves 90% renewable adoption but with slightly lower efficiency (PUE 1.18). AWS also reaches 90% renewables, excels in operational scale, but is less transparent in carbon reporting.

4.3 Key Findings and Implications

GCP emerges as the top performer for green computing, excelling in renewables and efficiency. Azure is notable for strong carbon goals and enterprise adaptability, while AWS demonstrates leadership by scale but still faces transparency challenges. Together, the tables and figures clearly demonstrate performance gaps and distinctive strengths among providers, directly supporting the research hypothesis that significant differences exist in sustainability outcomes.

5. CHALLENGES & LIMITATIONS

5.1 Data Gaps and Lack of Transparency

A key challenge in comparing green computing practices among AWS, Azure, and GCP is the variability in data transparency and disclosure. Providers differ in how frequently and deeply they

report sustainability metrics; Google Cloud offers real-time dashboards and granular data, while AWS and Azure tend to release annual summaries with less third-party verification. The absence of standardized reporting formats, especially for metrics like water usage effectiveness and supply chain emissions, makes it difficult to validate claims and accurately benchmark progress. Figure 3 below illustrates the varying depth of sustainability reporting and transparency levels among the providers.

Figure 3: Funnel chart illustrating the depth of sustainability reporting (Transparency Level) among cloud providers. Source: Provider Reports (2023).

5.2 Regional Differences and Unreported Metrics

Significant disparities also exist at the regional level, where energy mix and regulatory context can affect local data center sustainability. Providers' global averages may hide variations, with some regions relying more on non-renewable energy. Legacy operations and incomplete reporting further contribute to gaps in comparable metrics.

5.3 Methodological and Interpretive Limitations

This research relies on publicly available data, which may lack consistency and detail due to selective provider disclosure and rapidly evolving technology. The limitations of using only secondary data, coupled with differences in measurement standards, mean that conclusions drawn here reflect the best available information as of 2023–2025.

6. ORGANIZATIONAL AND CULTURAL PRACTICES

The effectiveness of green computing initiatives in cloud platforms is shaped not only by technology but also by organizational culture and internal practices. Amazon Web Services (AWS) integrates sustainability goals within its operations and leadership incentives, Microsoft Azure combines policy direction with employee involvement and transparency tools, while Google Cloud Platform (GCP) champions open communication, measurable targets, and innovation through cross-team collaboration. The following matrix summarizes key organizational and cultural features of each provider.

Table-2: Organizational and Cultural Sustainability Practices among AWS, Azure, and GCP.

	AWS	Azure	GCP
Renewable Energy	✓	✓	✓✓✓ (Best)
Reporting	Annual Reports	Sustainability Calculator	Public Dashboard
Employee Culture	Incentives	Green Teams	Hackathons
Transparency	Medium	High	Very High

7. FUTURE SCOPE OF THE STUDY

7.1 Region-Level Sustainability and Scope 3 Emissions: Future research should focus on region-specific sustainability reporting and measure supply chain (Scope 3) emissions to provide a more accurate and complete view of environmental impact across cloud platforms.

7.2 Evaluate AI and Edge Computing Efficiency Impacts: There is significant potential in exploring how advanced AI-driven systems and edge computing architectures can optimize energy usage and operational efficiency for greener cloud data centers.

7.3 Develop Unified Global Metrics and Foster Collaboration:
Advancing universal sustainability benchmarks, launching industry-wide circular economy initiatives (such as e-waste reduction), and strengthening academic, government, and industry partnerships can accelerate green digital infrastructure worldwide.

8. CONCLUSION

This research presents a comprehensive comparative analysis of green computing across Amazon Web Services, Microsoft Azure, and Google Cloud Platform, focusing on environmental metrics, technical strategies, and organizational practices. The study highlights clear differences in renewable energy adoption, energy efficiency, carbon neutrality goals, transparency, and use of AI-driven optimization, with GCP leading in renewables and reporting, Azure excelling in enterprise integration and adaptive policies, and AWS distinguished by scale and operational breadth. Despite impressive progress, challenges persist—including gaps in data transparency, regional reporting accuracy, and Scope 3 emissions disclosure—which complicate direct benchmarking and objective assessments. The findings underscore the necessity of unified global sustainability metrics, deeper industry collaboration, and the adoption of innovative

technologies such as AI and edge computing for future advancements. By synthesizing quantitative analysis with qualitative insight, this work provides actionable recommendations for organizations and policymakers while affirming the crucial role of environmental stewardship and continuous innovation in shaping the sustainable evolution of cloud infrastructure. Ultimately, the way forward for green cloud computing lies in breaking silos, elevating transparency, and embracing cross-disciplinary partnerships that enable the digital economy to align with global climate goals.

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