

GREEN CLOUD COMPUTING: A COMPREHENSIVE REVIEW OF ECO-FRIENDLY COMPUTING STRATEGIES

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ABSTRACT

As the demand for cloud computing continues to increase, the environmental impact of data centers is becoming a growing concern. Green cloud computing has emerged as a solution to address this issue, reducing the carbon footprint of cloud computing while maintaining its performance and functionality. This paper comprehensively reviews eco-friendly computing strategies for Green Cloud Computing, such as virtualization, consolidation, dynamic resource allocation, energy-efficient hardware design, Renewable energy sources, and energy-efficient cooling systems. Green computation algorithms, which are an integral component of the green cloud computing movement that aims to reduce the carbon footprint of computing systems, are explored. The algorithms are designed to optimize energy efficiency, reduce power consumption, and ensure the efficient use of resources while maintaining performance and functionality. The algorithms are essential to widely adopt eco-friendly computing strategies and create a more sustainable future for cloud computing.

Keywords: Green cloud computing, virtualization, strategies for optimizing energy, green computational algorithm.

INTRODUCTION

Cloud computing has become an integral part of modern-day computing, with an increasing number of businesses and individuals relying on cloud-based services for their computing needs. Concerns concerning the environmental effect of cloud data centers have arisen due to the massive increase in energy usage brought on by the expanding demand for cloud computing. As a result, there is a rising concern in green cloud computing, which tries to improve computing's speed and usefulness while lowering its carbon impact. For various reasons, Green Cloud Computing has emerged as a priority for businesses and governments. Firstly, adopting environment-friendly cloud computing practices can assist organizations in

accomplishing their sustainability objectives and enhancing their corporate social responsibility image. Secondly, by implementing energy-efficient computing strategies, companies can achieve cost savings by reducing the energy consumption of cloud data centers (Alarifi 2020). Thirdly, regulations and policies introduced by governments mandate businesses to decrease their carbon emissions, necessitating the adoption of Green Cloud Computing for compliance purposes.

Green Cloud Computing encompasses a range of eco-friendly computing strategies, including energy-efficient hardware design, virtualization and consolidation techniques, dynamic resource allocation and load balancing, and renewable energy sources. By implementing

these strategies, data centers can reduce their energy consumption and carbon emissions while maintaining high performance and availability.

LITERATURE REVIEW

Ashfaq Ahmad et al. (Ahmad 2021) delved into the escalating significance of Green Cloud Computing amid the pervasive use of cloud services, driven by environmental concerns arising from massive data center energy consumption. The paper conducted a systematic literature review, identifying nine challenges and 63 practices client organizations face in adopting green cloud solutions. The research aims to develop a comprehensive framework employing robust soft computing techniques like Fuzzy logic or AHP to guide clients in embracing environmentally sustainable cloud environments.

Da Chen et al. (Chen 2022) conducted a comprehensive analysis of green building research, focusing on its natural and harmonious attributes, providing a healthy living space while minimizing resource use and environmental impact. Using literature from CNKI and Web of Science databases, the study maps research trends, identifies hotspots, and predicts future developments, aiming to contribute to theoretical progress and practical optimization in green construction.

Ebtesam H Alharbi et al. (Alharbi 2020) addressed the growing significance of Green Computing, particularly in the context of cloud computing's environmental impact. Focused on Saudi Arabia, the paper proposed a framework highlighting factors influencing the adoption of green computing by current and future cloud providers. This framework is a guideline promoting best practices for achieving green computing objectives.

Geetanjali et al. (Geetanjali 2022) introduced "Green Cloud Computing," merging Green and Cloud Computing to achieve cost-efficient

cloud services with minimal environmental impact. Investigating the historical energy challenges of data centers, the paper emphasizes businesses' shift to save power, leveraging technologies like Blockchain and IoT. It underscores the versatility of Green Cloud Computing across various applications. Mansoor Syed Raza et al. (Raza 2021) proposed and implemented an exploration of Green Cloud Computing (GCC), emphasizing its advantages in power management and energy efficiency. The paper delves into intelligent techniques applied to cloud computing, analyzing them based on parameters like resource utilization and response time. It highlights a positive trend towards greener cloud computing development.

Ning Hu et al. (Hu 2021) introduced Deep-Green, a dispersed energy-efficient computing paradigm designed for the Industrial Internet of Things (IIoT). Addressing the energy consumption challenges in cloud-based industrial control models, Deep-Green optimizes computing and network resources by integrating data transmission and processing. Utilizing an energy-efficient task scheduling algorithm, container service technology, and programmable protocol stack, Deep-Green shifts data processing from the cloud to on-site controllers, reducing computing load and communication overhead. Experimental results demonstrate its effectiveness in simplifying network topology and reducing devices in the IIoT's edge layer.

Rajesh Doss et al. (Doss 2022) explored the convergence of Green and Cloud Computing in the ICT sector, termed "green cloud computing." Based on existing research, the study highlights cloud servers as environmentally friendly for services. Three case studies on enterprises offering green hosting services reveal market dynamics and end-users need to drive demand for green cloud solutions, emphasizing efficiency indicators and service level agreements.

Seyyed Mohsen Seyyedsalehi et al. (Seyyedsalehi 2022) introduce a novel approach, the aware genetic algorithm first fit (AGAFF), for optimizing virtual machine (VM) placement in multi-datacenter (DC) cloud environments. Addressing the complexity of this NP-hard problem, AGAFF is a context-aware genetic algorithm that minimizes energy usage, intra-DC traffic for big data tasks, and VM live migrations while maximizing CPU and RAM usage. The algorithm significantly reduces energy consumption by approximately 61% on average compared to four other algorithms, showcasing improvements in job execution time and a decrease in service level agreement violations. Sukhpreet Kaur et al. (Kaur 2021) proposed an investigation into Green Cloud Computing (GCC) within the context of the growing importance of cloud technology. The paper outlines techniques for reducing energy consumption, analyzing parameters for cost reduction, and decreasing carbon emissions. It emphasizes creating an environmentally safe, fault-tolerant "Green cloud" with enhanced reliability and scalability. Yongjian Liao et al. (Liao 2020) introduce a new and secure approach, considering the recyclable utilization of resources for the cloud server. The proposed method reduces total overhead for the cloud server, independent of the number of users requesting outsourced decryption for the same ciphertext, while also decreasing users' decryption computation costs. Additionally, the approach is extended to a Recyclable Cloud Computing Architecture (RCCA)-secure ABE-OD scheme.

STRATEGIES FOR OPTIMIZING ENERGY IN GREEN CLOUD COMPUTING

Cloud data centers are energy-intensive facilities that require significant amounts of electricity to power and cool their IT equipment. The increasing demand for cloud

services and the rapid growth of data centers has resulted in significant energy consumption and carbon emissions. To address these challenges, several strategies can be employed to optimize energy consumption in cloud data centers:

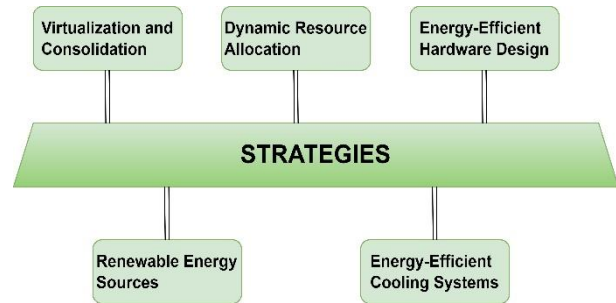


Fig 1: Strategies for Optimizing Energy (Daigneault 2021)

Virtualization and consolidation:

Several virtual instances can be created on a single physical server using virtualization, improving resource usage and lowering the need for real servers. This leads to significant energy savings and reduces the carbon footprint of cloud data centers. Consolidation involves combining workloads on a smaller number of servers, resulting in more efficient use of resources and lower energy consumption.

Dynamic resource allocation:

Dynamic resource allocation involves allocating resources in real-time based on the current workload demand. This ensures that resources are only active when needed, reducing energy consumption and improving energy efficiency. Techniques such as load balancing, automatic scaling, and virtual machine migration can be used to implement dynamic resource allocation (Hou 2019).

Energy-efficient hardware design:

Energy-efficient hardware design involves designing and using hardware that consumes less power while still delivering the required performance. This includes using low-power processors, energy-efficient cooling systems, and power management technologies such as dynamic voltage and frequency scaling.

Renewable energy sources:

Renewable energy sources like solar, wind, and hydropower are used to decrease the carbon footprint of cloud data centers. To power their data centers, cloud service companies may acquire renewable energy credits or construct their renewable energy facilities.

Energy-efficient cooling systems:

Cooling systems significantly contribute to energy consumption in data centers. Employing more energy-efficient cooling systems, such as air economizers and evaporative and liquid cooling systems, can result in significant energy savings.

Virtualization and Consolidation

Virtualization and consolidation techniques, which are crucial for cloud resource optimization, make it possible to achieve the optimal utilization of hardware resources and the reduction of energy consumption. This method aims to reduce the number of physical servers needed, consolidate several applications onto a single server, and maximize resource use. With this strategy, the energy footprint of cloud computing may be significantly reduced. Several virtual machines may operate on a single physical server thanks to virtualization, a fundamental enabler of consolidation strategies. Each VM can run a separate application, operating system, and software stack, providing the illusion of running on dedicated hardware. Virtualization enables resource sharing by consolidating multiple

applications onto a single server, reducing hardware requirements, and optimizing resource utilization. Consolidation techniques involve grouping applications with similar resource requirements onto a single server to maximize resource utilization. This approach can improve server utilization rates from around 5-10% to over 80%, significantly reducing energy consumption and lowering costs. Table 1 shows several virtualization and consolidation techniques that can optimize cloud resources, including server consolidation, workload consolidation, and dynamic consolidation.

Table 1: Virtualization and Consolidation Techniques (Hu 2021).

S. No.	Techniques	
	Names	Explanation
1.	Server consolidation	It entails consolidating several physical servers into fewer, more potent ones. This strategy can simplify management and use less energy by significantly lowering the number of physical servers needed.
2.	Workload consolidation	It involves grouping workloads with similar resource requirements onto a single server. This approach can improve resource utilization and reduce energy consumption by enabling more efficient use of hardware resources.
3.	Dynamic consolidation	It involves monitoring resource utilization and automatically migrating workloads between servers to optimize resource utilization. This approach can improve resource utilization and reduce energy consumption while maintaining application performance.

In addition to consolidation techniques, virtualization can also be used to optimize resource utilization by allocating and deallocating resources as needed. Using this method, it is possible to create VMs with

various resource needs, making it possible to utilize hardware resources effectively and use less energy.

Dynamic Resource Allocation and Load Balancing

They are essential for optimizing cloud resources and improving energy efficiency. These strategies involve dynamically allocating resources to meet the changing demands of workloads, optimizing resource utilization, and reducing energy consumption. Dynamic resource allocation involves monitoring resource utilization and allocating resources to workloads as needed. This approach enables the efficient use of hardware resources, reducing energy consumption and lowering costs. Dynamic resource allocation can be achieved through orchestration and automation tools, which can help manage resource allocation and ensure optimal performance.

Load balancing is another essential strategy for optimizing cloud resources and improving energy efficiency. Load balancing involves distributing workloads across multiple servers to ensure optimal resource utilization and prevent contention. By evenly distributing workloads, load balancing can help optimize resource utilization and reduce energy consumption. Table 2 shows several load-balancing techniques that can be used to optimize cloud resources.

Table 2: Load Balancing Techniques (Martinez 2021).

S. No.	Load Balancing Techniques	
	Names	Explanation
1.	Round-robin load balancing	It involves evenly distributing workloads across multiple servers sequentially. This approach ensures that each server receives an equal number of workloads, optimizing resource utilization and preventing contention.

S. No.	Load Balancing Techniques	
	Names	Explanation
2.	Least connections load balancing	It involves distributing workloads to the server with the least active connections. This approach ensures that workloads are evenly distributed, optimizing resource utilization and improving performance.
3.	IP hash load balancing	It entails allocating workloads by the request's source IP address. This strategy optimizes resource usage and boosts performance by ensuring that requests from the same IP address are always sent to the same server.
4.	Content-based routing	It involves distributing workloads based on the content of the request. This approach can help optimize resource utilization and improve performance by ensuring that workloads with similar resource requirements are directed to the same server.

In addition to load balancing, monitoring resource utilization and dynamically allocating resources to workloads as needed is essential. This approach can help optimize resource utilization, reduce energy consumption, and improve performance. Several tools and technologies can be used to implement dynamic resource allocation and load balancing in cloud computing environments:

Containerization involves packaging applications and their dependencies into self-contained units that can be easily deployed and managed. This approach can help simplify resource allocation and load balancing by providing a standardized way to deploy and manage applications.

Orchestration tools, such as Kubernetes and Docker Swarm, provide a way to manage and automate the deployment and scaling of containerized applications. These tools can help optimize resource utilization and improve performance by dynamically allocating resources and balancing workloads.

Automation tools, such as Ansible and Puppet, can automate the management and configuration of cloud resources, including load balancing and resource allocation. These tools can help optimize resource utilization and reduce energy consumption by automating routine tasks and ensuring optimal performance.

Energy-efficient hardware design

Energy-efficient hardware design and utilization are critical aspects of Green Cloud Computing. As cloud data centers consume vast amounts of energy, optimizing the hardware and infrastructure design can result in significant energy savings and reduce the carbon footprint of cloud computing. This section will review some of the energy-efficient hardware design strategies that can be implemented in cloud data centers.

The servers are one of the most significant contributors to energy consumption in cloud data centers. Servers are the primary computing components that perform data processing, storage, and networking tasks. However, traditional server designs are not optimized for energy efficiency and consume a significant amount of energy even when idle. One of the strategies for optimizing server energy efficiency is using low-power processors, such as ARM processors. ARM processors consume significantly less power than x86 processors and can perform many of the same computing tasks. Cloud data centers can reduce their energy consumption by using low-power processors without sacrificing performance.

Renewable energy source

Renewable energy sources have gained significant attention in recent years as a potential solution for decreasing the carbon footprint of cloud data centers. As cloud data centers grow in size and number, the energy

demand is increasing rapidly. Conventional energy sources are finite and contribute to greenhouse gas emissions, making it imperative to explore alternative renewable energy sources, such as solar, wind, hydro, and geothermal energy, which are sustainable and environmentally friendly, making them a promising solution for powering cloud data centers.

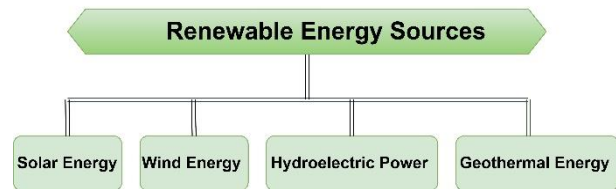


Fig 2: Renewable Energy Source (Wen 2020).

Solar energy: Solar panels can be installed on the rooftops of data centers, generating clean and sustainable energy to power their operations. Solar energy is an attractive solution due to its availability and scalability. The installation of solar panels can also reduce energy costs and provide a source of revenue for data center operators through the sale of excess energy to the grid.

Wind energy: Wind turbines can be installed near data centers, generating clean and sustainable energy to power their operations. Wind energy is attractive, scalable, and low-cost. It can also provide a source of revenue for data center operators by selling excess energy to the grid.

Hydroelectric power: Hydroelectric power is generated through water turbines that convert the energy of flowing water into electricity. Hydroelectric power is a reliable and sustainable energy source, making it a promising solution for powering cloud data centers (Madan 2022).

Geothermal energy: Geothermal energy is generated through underground heat harnessed through geothermal power plants. Geothermal energy is a sustainable and reliable energy

source, making it a promising solution for powering cloud data centers.

Energy-efficient cooling systems

In virtualization, fewer physical servers are needed, requiring less energy, and more virtual servers may run on a single physical server. Virtualization allows dynamic resource allocation and load balancing to be achieved, enabling cloud data centers to maximize their resource and power usage. Using energy-efficient cooling systems is another strategy for reducing energy consumption in cloud data centers. Cooling systems are required to maintain a stable temperature in the data center, and traditional cooling systems consume a significant amount of energy. However, new cooling technologies like liquid cooling can significantly reduce energy consumption while maintaining optimal data center temperatures. Liquid cooling can be more efficient than air cooling, as liquids have a higher heat capacity and can transport heat more efficiently. Liquid cooling systems can also enable server overclocking, improving performance without increasing energy consumption.

GREEN COMPUTATION ALGORITHMS

By incorporating the given algorithms into cloud computing processes, cloud providers can reduce their energy consumption and carbon footprint without compromising performance. Table 3 shows some of the green computation algorithms.

Table 3: Green Computation Algorithms (Hataba 2022).

S. No.	Algorithms	
	Names	Explanation
1.	Dynamic Voltage Scaling algorithm	This method reduces energy usage while preserving performance by adjusting the processors' voltage and frequency to fit the job's demands.
2.	DVFS	This method lowers processor energy consumption by altering processors' operating frequency and voltage in real-time according to the workload demand. The program can cut energy usage while achieving performance goals by reducing frequency and voltage when workload demand is low.
3.	Consolidation	By running several virtual computers on one physical server, the application of this consolidation strategy can help reduce the consumption of energy. This may result in fewer servers, cutting down on the energy used. This can be done using the virtualization method, which enables multiple VMs to be hosted on a single physical server.
4.	Sleep Mode	This algorithm lowers energy usage by putting idle servers into a low-power sleep mode. The servers can be swiftly woken up to handle increased workload needs. Energy use is reduced without compromising responsiveness.
5.	Energy-Aware Routing Algorithm	This algorithm routes network traffic through the most energy-efficient paths to reduce power consumption.
6.	Task Scheduling	This algorithm plans the execution of tasks to minimize energy consumption. To reduce the time, a server must be active, related operations can be combined, or processes can be scheduled when energy usage is lower, like at night (Wazid 2020).

7.	<i>Energy-Aware Web Server Algorithm</i>	This method considers various system components' workload and energy usage to maximize web server performance while decreasing energy consumption.
8.	<i>Energy-Efficient Task Scheduling Algorithm</i>	This algorithm plans activities to be carried out while maximizing energy efficiency, considering the power requirements of various system components.

CONCLUSION

Energy-intensive buildings and cloud data centers need a lot of electricity to run and cool their IT equipment. The rapid growth of data centers and the increasing demand for cloud services have resulted in significant energy consumption and carbon emissions. Green cloud computing is an emerging field that aims to reduce the environmental impact of cloud computing by implementing eco-friendly computing strategies such as virtualization, consolidation, Dynamic resource allocation, Energy-efficient hardware design, Renewable energy sources, and Energy-efficient cooling systems.

Green computation algorithms are an essential part of the green cloud computing movement that aims to reduce the carbon footprint of computing systems. These algorithms are designed to optimize energy efficiency and reduce power consumption while maintaining the performance and functionality of the system. The strategies used in green computation algorithms vary widely and include techniques such as DVS, DVFS, Consolidation, Sleep Mode, Energy-Aware Routing, Task Scheduling, Energy-Aware Web Server, and Energy-Efficient Task Scheduling. Green computation algorithms significantly impact energy efficiency and the environmental impact of cloud computing. By implementing these algorithms, companies can reduce their carbon footprint, save energy costs, and improve their environmental sustainability. The continued development and implementation of green computation algorithms are essential to create a more sustainable and eco-friendly future for cloud computing.

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