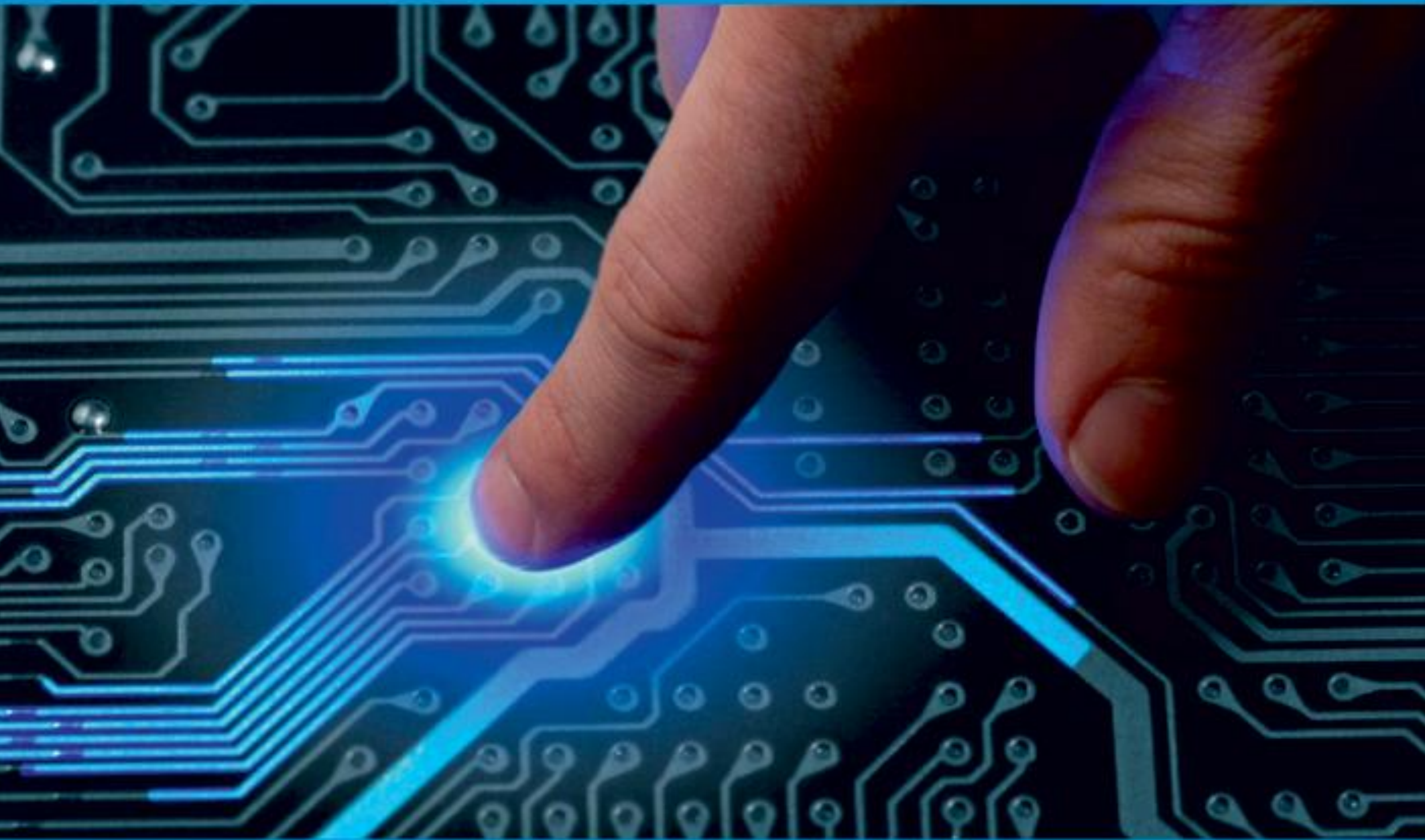
IJIRCCE

e-ISSN: 2320-9801 | p-ISSN: 2320-9798



# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

## IN COMPUTER & COMMUNICATION ENGINEERING

Volume 12, Issue 5, May 2024

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

**Impact Factor: 8.379**

| e-ISSN: 2320-9801, p-ISSN: 2320-9798| www.ijircce.com | |Impact Factor: 8.379 | Monthly Peer Reviewed & Referred Journal |

|| Volume 12, Issue 5, May 2024 ||

| DOI: 10.15680/IJIRCCE.2024.1205182 |

# Green Cloud Computing: Innovating for Sustainable, Low-Impact Data Management.

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**ABSTRACT:** Cloud computing is the internet-based provision of computer services. The usage of some cloud services by individuals and businesses is expanding quickly. The rising demand for cloud infrastructure has led to a notable rise in the energy consumption of data centers. Reducing energy usage is essential to lowering carbon dioxide emissions, hence it must be addressed. Given that green cloud computing's main objective is to maximize energy efficiency, it is acknowledged as a potential solution to this issue. This paper presents green cloud computing alternatives for energy savings in addition to defining cloud computing with the key cloud service models, deployment strategies, and computing platforms. After that, these solutions were categorized based on how well they reduced energy.

**KEYWORDS:** Cloud Computing, Carbon Dioxide Emission, Cloud Infrastructure, Cloud services, Cloud Service Models, Data Centers, Energy efficiency.

## I. INTRODUCTION

Nowadays cloud computing is one of the well-known technologies that has become widely used worldwide. It provides a range of services, including data storage and access, flexibility, scalability, and adaptability, to its beneficiaries in exchange for an optimal quantity of money or fees.

The primary benefit of cloud computing is its ability to provide users with uninterrupted online access to any kind of service they require, including compute and data storage. The growing consumer demand for cloud services enables the cloud service provider to set up numerous data centers in multiple locations. Lots of energy are needed in these data centers to run equipment like cooling fans for processors, lights, cooling systems, and network peripherals.**[3]** Green computing, on the other hand, is the successful integration of environmentally friendly technologies or green efforts with computer systems. In Green computing includes not just resource allocation but also deployment, optimization, virtualization, and energy management. These days, green computing is a power and energy-saving endeavor. While there exist several obstacles and difficulties relating to cloud computing and green computing, the most common and noteworthy ones are related to initiatives, awareness, and monetary concerns. Because of the amazing and great benefits of computing, applications have become prevalent in many other new fields and places.

In line with the cloud service model, large pools of high-performance computing resources and high-capacity storage devices must be provided by the service provider and then distributed to the end users when necessary.

There are several different cloud service models. However, the clients of a service store the information in the service and have access to a pool of computing resources as needed in most cases. A service provider can make software programs created by a customer available through the service provisioned. For the cloud service paradigm to operate there has to be a quick network connection between the end user and service provider infrastructure. There are numerous definitions for cloud computing, and prospective future services are still up for debate in the world of information technology. The sustainable use of computers along with associated resources is referred to as "green cloud computing". Using servers, central processing units, and energy-efficient peripherals are a few examples of such strategies. resources, as well as disposing of technological waste safely. Green computing refers to "the science and practice of developing, industrializing, using, and disposing of computers, servers, and associated subsystems with low or no environmental impact." This covers interface systems, networking, storage devices, printers, and monitors. Green computing, like green chemistry, wants to reduce the use of hazardous chemicals, improve energy efficiency over the course of the product's life, and encourage the recycling or biodegradability of industrial waste. **[1]**

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**Green Cloud Architecture**

Green cloud computing is a business concept that benefits both the environment and cloud providers. In addition to being better for the environment, green cloud computing increases the advantages for service providers by making effective use of the resources by requiring specific management practices and attributes. Cloud data centers, Green Cloud Providers (GCP), and cloud consumers collaborate in the planning of green cloud computing engineering. Cloud server centers offer services such as SaaS, PaaS, and IaaS. Designed to function as a cloud administration expert module, the Green Cloud Provider (GCP) is able to verify that the associated clouds are green by vetting the cloud foundation and duties. The GCP introduces the module level energy usage and monitors the power and resource management at every level meters.

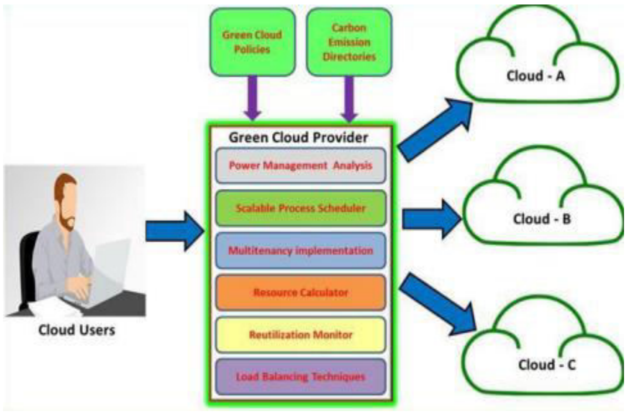


Fig 1: Green Cloud Computing Architecture **[11]**

## II. RESEARCH METHODOLOGY

**A. Scheduling Algorithms [3]**

Resource distribution and planning significantly influence performance in all areas of communications such as parallel, distributed systems, networking, and cloud computing. Researchers have proposed several procedures for scheduling, assigning and sizing all resources in the cloud. However, this paper focuses on three scheduling algorithms.

1. First come first serve
2. Round Robin
3. Shortest job first scheduling

**Description of algorithms**

**1.First come first serve:**

The First-Come, First-Served (FCFS) scheduling algorithm is a fundamental concept in computing, applied across various domains such as operating systems, disk management, and network packet scheduling. At its core, FCFS operates on a simple principle: tasks are serviced in the order they arrive, akin to standing in a line at a checkout counter. Upon arrival, tasks are placed at the end of the queue, and the processor or resource serves them sequentially, without any consideration of priority or other factors. While FCFS is easy to understand and implement, it may not always be the most efficient scheduling algorithm, particularly in scenarios where tasks have varying execution times or when prioritization is necessary. Despite its limitations, First-Come-First-Serve is a critical building block of scheduling algorithms and offers a foundation for understanding other more intricate scheduling algorithms.

**2.Round Robin:**

Round Robin is another popular scheduling algorithm used in operating systems and network environments. In Round Robin (RR), tasks are serviced in a cyclic order, where each task is given a fixed time slice or quantum to execute. If a task's execution is not completed within its time quantum, it is preempted, and the next task in the queue is selected for execution. The preempted task is then placed at the end of the queue to wait for its next turn.

Round Robin scheduling offers fairness and ensures that all tasks receive some CPU time, regardless of their priority or execution time. However, it may not be optimal for tasks with varying execution times, as short tasks may be repeatedly interrupted, leading to unnecessary overhead. The time quantum in Round Robin scheduling is a critical parameter that affects the algorithm's performance. A smaller time quantum provides more frequent task switching,

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reducing response time but increasing overhead due to context switches. On the other hand, a larger time quantum reduces context switch overhead but may lead to increased response time and less fairness among tasks.
Overall, Round Robin scheduling strikes a balance between fairness and responsiveness, making it suitable for time-sharing systems and environments where fairness is a priority. However, it may not be the best choice for real-time systems or scenarios with strict performance requirements.

**3.Shortest Job first scheduling:** Shortest Job First (SJF) is a scheduling algorithm employed in operating systems and task management to optimize task execution by prioritizing the shortest tasks first. This algorithm selects tasks based on their anticipated processing time, executing the shortest one before proceeding to longer ones. SJF aims to minimize the average waiting time for tasks in the system, thereby enhancing system efficiency. Upon the arrival of tasks, SJF assesses their estimated processing times, either known or predicted. It then schedules tasks for execution in ascending order of their processing times. This approach ensures that shorter tasks are processed promptly, leading to reduced waiting times and improved system performance. While SJF is effective in minimizing waiting times, it may encounter issues with long-running tasks that could potentially starve as shorter tasks continuously preempt them. Despite this drawback, SJF remains a valuable scheduling algorithm, particularly in scenarios where tasks' execution times are well-defined and predictable.

**B. Heuristic Algorithm:**
The best fit decreasing algorithm and the balance best fit decreasing algorithm are two examples of heuristic algorithms. The bin-packing issue is the best fit reducing method.

This is difficult in NP. This approach assigns the virtual machine to the real machine first. The weight and usage of each virtual machine are grouped using a best fit decreasing technique. The virtual machines with the most resources are the first to start. The resources or virtual machines are arranged based on their sizes via the balanced best fit decreasing method, which is an enhanced version of the best fit decreasing algorithm. As a result, less energy is consumed.

**C. Meta heuristic algorithms**
This is founded on the consolidation of virtual machines. A method that aids in energy conservation is virtual machine consolidation. Two methods are employed in this optimization technique: the best fit decreasing algorithm and the other is Algorithm for the ant colony system. The ant colony system uses a large number of CPUs, virtual machine monitors, real computers, and virtual machines. The local and global agents are the two categories of agents that make up the system model.

The local agent indicates the current resource use in order to resolve the PMs Status detection sub-problem. The Ant colony system method is used by the global agent, which acts as a supervisor in the interim to optimize the placement of the virtual machines.

An additional meta heuristic approach for minimizing energy is the harmony search algorithm.

**D. Energy conservation using optimization**
The energy conservation approach described utilizes a two-layer optimization framework consisting of the Green Manager Layer (GML) and the Cloud Manager Layer (CML). Each layer performs specific functions to efficiently manage resources and minimize energy consumption in cloud computing environments.

At the Cloud Manager Layer (CML) level, resources are managed in a comprehensive manner. This involves selecting all suitable resources from the pool of available resources. These resources could include servers, storage, networking devices, and other infrastructure components. The primary goal of CML is to ensure that all required resources are identified and allocated appropriately to meet the demands of tasks and applications running in the cloud environment.

On the other hand, the Green Manager Layer (GML) operates at a higher level of abstraction. GML focuses on selecting the best resources from the subset identified by CML. This selection process considers various characteristics and criteria to optimize resource utilization while minimizing energy consumption. These characteristics may include:

1. Location: The physical location of resources, considering factors such as proximity to users, data centers, or other resources, to minimize latency and network traffic.

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2. Average Service Response Time: Evaluating the historical performance of resources in terms of response time to ensure efficient task execution and user satisfaction.

3. Length of Queue: Monitoring the length of queues for resource allocation to prevent bottlenecks and ensure timely processing of tasks.

4. Service Response and Request Time: Analyzing the time taken to respond to service requests and allocate resources.

## III. TECHNOLOGIES FOR ECO-FRIENDLY CLOUD COMPUTING

The following technologies can be integrated into the existing cloud models in order to make them Green. The technologies are**:[11]**

**1. Virtualization:**
Virtualization is a cornerstone strategy for green cloud computing, aimed at maximizing resource utilization and reducing energy consumption. Through virtualization, multiple virtual machines (VMs) can run on a single physical server, allowing for better utilization of computing resources. This consolidation reduces the number of physical servers required, leading to significant energy savings by lowering power consumption, cooling needs, and the overall data center footprint. Additionally, virtualization enables dynamic allocation and scaling of resources based on demand, further enhancing efficiency and reducing idle capacity. By abstracting hardware resources from software applications, virtualization optimizes infrastructure utilization, promoting a more sustainable and environmentally friendly cloud computing ecosystem.

**2.Data Center Optimization:**
Data center optimization focuses on enhancing the energy efficiency of data centers, which are the backbone of cloud computing infrastructure. This strategy involves implementing various technologies and best practices to minimize power consumption and improve cooling efficiency. Techniques such as hot/cold aisle containment, efficient cooling systems, and advanced power distribution units help optimize airflow and temperature management, reducing energy waste. Furthermore, utilizing energy-efficient hardware components, such as low-power processors and solid-state drives, contributes to overall energy savings. Data center optimization also involves regular monitoring and management of power usage effectiveness (PUE) and other key performance indicators to identify areas for improvement and ensure continuous efficiency gains.

**3.Renewable Energy Integration:**
In cloud computing, the incorporation of renewable energy is very important for sustainability. This is because clouds consume a lot of energy and they contribute in polluting the atmosphere. Consequently, to bring emissions down, it is highly recommended to power them using green sources such as solar, wind or hydro. To include sustainable power in the running of data center; on-site generation, agreements with renewable energy sellers, as well as joining green electricity initiatives could work. Besides, the other possible way is to use batteries or flywheels as energy storage solutions to store the surpluses which can be used in peak demand periods, or in the event of unavailability of other renewable sources. By prioritizing renewable energy integration, cloud providers can not only reduce their environmental impact but also contribute to the global transition towards a more sustainable energy future.

**4.Power Management:**
Power management technologies are essential in green cloud computing to optimize energy usage and reduce waste. These technologies encompass a range of approaches, including dynamic voltage and frequency scaling (DVFS), which adjusts the operating frequency and voltage of processors based on workload demands to minimize power consumption without sacrificing performance. Advanced power management features in hardware components, such as servers and networking devices, enable intelligent power management policies and fine-grained control over power usage. Additionally, techniques like power capping and load balancing help distribute workloads efficiently across servers to prevent overloading and maximize energy efficiency. By implementing power management technologies, cloud providers can achieve significant energy savings while maintaining high levels of performance and reliability.

**5.Resource Allocation:**
Effective resource allocation technologies are crucial for optimizing resource utilization in green cloud computing environments. These technologies dynamically allocate computing, storage, and network resources based on workload requirements, ensuring that resources are efficiently utilized without unnecessary idle capacity. Techniques such as

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virtual machine (VM) migration and workload consolidation enable automatic scaling and redistribution of resources to match changing demand patterns. Furthermore, intelligent scheduling algorithms, such as load-aware and predictive scheduling, help optimize resource allocation decisions to minimize energy consumption while meeting service-level objectives. By leveraging resource allocation technologies, cloud providers can maximize the utilization of their infrastructure, reduce energy waste, and improve overall operational efficiency.

**6.Energy Monitoring:**
Energy monitoring technologies play a critical role in green cloud computing by providing visibility into energy usage across data centers and IT infrastructure. These technologies encompass energy monitoring systems and software tools that collect, analyze, and report energy consumption data in real-time. By monitoring energy usage at various levels, including servers, cooling systems, and networking equipment, cloud providers can identify inefficiencies, pinpoint areas of high energy consumption, and implement targeted optimization measures. Energy monitoring also enables proactive energy management strategies, such as demand response and peak shaving, to reduce energy costs and enhance grid stability. By integrating energy monitoring technologies into their operations, cloud providers can gain insights into their energy usage patterns, track progress towards sustainability goals, and make informed decisions to optimize energy efficiency.

**7.Cooling Techniques:**
Cooling techniques are essential for maintaining optimal operating temperatures in data centers while minimizing energy consumption. Green cloud computing emphasizes the use of energy-efficient cooling technologies to reduce the environmental impact of data center operations. These techniques include advanced cooling systems, such as airside economization and liquid cooling solutions, which leverage ambient air or water for heat dissipation instead of traditional mechanical cooling methods. Additionally, containment strategies, such as hot/cold aisle containment and chimney cabinets, help isolate and manage airflow to improve cooling efficiency and reduce energy waste. Furthermore, predictive analytics and thermal management tools enable proactive monitoring and adjustment of cooling systems based on environmental conditions and workload fluctuations. By adopting energy-efficient cooling techniques, cloud providers can reduce their carbon footprint, lower operational costs, and improve overall sustainability.

## IV. DIFFICULTIES ENCOUNTERED WHEN IMPLEMENTING ECO-FRIENDLY CLOUD COMPUTING:

Cloud computing and green computing share many issues and difficulties, such as:
All parties involved in the computer industry, including consumers, manufacturers, and organizations, need to be aware of green computing. Green computing policies must be standardized by the governments of all countries. Many organizations that promote eco-friendly or green initiatives still do not have green computing in their plans due to a lack of user awareness.
While recycling is possible for some materials, green computing shows how to repurpose resources.
Challenges in Using Green Cloud Computing [1]

**1.Data Security and Privacy:**
**Challenges:** Security and privacy of data should be guaranteed while implementing energy-efficient measures. In green cloud computing, this can be viewed as a key challenge. Primarily, unauthorized access, data sovereignty, and data breaches cause worry among various cloud providers, especially when data is stored and processed within shared environments.

**Solutions:** In order to tackle these challenges, cloud providers have to implement strong security measures such as encryption, access controls mechanisms and carry out security audits on a regular basis. Additionally, adopting compliance frameworks such as GDPR (General Data Protection Regulation) and ISO 27001 can help ensure adherence to data privacy regulations. Cloud users should also prioritize selecting reputable providers with strong security protocols and transparent data handling practices.

**2.E-waste Management:**
**Challenges:** The rapid pace of technological advancement in cloud computing often leads to the generation of electronic waste (e-waste) as outdated hardware and infrastructure components are replaced. Improper disposal of e-waste can have harmful environmental and health impacts due to the presence of hazardous materials.

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**Solutions:** Cloud providers can implement sustainable e-waste management practices by promoting recycling, refurbishment, and responsible disposal of electronic equipment. Adopting circular economy principles, such as designing products for longevity and recyclability, can minimize e-waste generation. Furthermore, partnering with certified e-waste recycling facilities and adhering to regulatory guidelines for e-waste disposal helps ensure environmentally responsible practices.

**3. Greenwashing:**
**Challenges:** Greenwashing, or the practice of exaggerating or misrepresenting environmental sustainability efforts, poses a challenge in green cloud computing. Some providers may claim to offer environmentally friendly services without implementing substantive measures, leading to consumer mistrust and confusion
.
**Solutions:** To combat greenwashing, transparency and accountability are essential. Cloud providers should provide clear and verifiable information about their sustainability initiatives, including energy efficiency metrics, renewable energy usage, and carbon footprint reduction efforts. Independent third-party certifications, such as LEED (Leadership in Energy and Environmental Design) and Energy Star, can validate a provider's environmental credentials. Additionally, industry collaboration and standards development help establish consistent criteria for evaluating and comparing green cloud services, enabling consumers to make informed choices based on genuine sustainability performance.

## V. CONCLUSION

Green cloud computing is acknowledged as a broad and exciting area of research. By leveraging various resources, it has generated optimal approaches to resource utilization, networking infrastructure enhancement, task scheduling, resource allocation, and all in favor of making them more energy efficient. Several research projects and technologies that try to improve the energy efficiency of various aspects of green cloud computing were categorized, and their energy efficiency outcomes were compared. Based on this review, it is determined that power management solutions and energy efficiency play a significant role in the shift from traditional cloud computing technologies to more environmentally friendly and sustainable ones.

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