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Towards Sustainable Computing: Recent Advances and Challenges in Green Cloud Computing

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Abstract-

The concept of "green cloud computing" is the young field that emphasises the efficient use of data centre computing assets with a goal of reducing the carbon footprint and adverse environmental effects. This article provides a thorough overview of the most recent findings and developments in green cloud computing. The manuscript covers a wide range of topics, including virtualization methods, eco-friendly networks, and environmentally sustainable computing procedures. The article also examines the difficulties and opportunities associated with green cloud computing and suggests possible lines of inquiry for further study.

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Key Words: Cloud, Cloud Computing, Green Cloud Computing, Virtualisation, Energy efficiency

I. INTRODUCTION

The methods by which individuals and organisations access and make use of computing resources have undergone a significant transformation thanks to the use of cloud computing. But there are now significantly more data centres due to the growing demand for these resources. These facilities Consume substantial amounts of power and release significant quantities of carbon dioxide. Green Cloud Computing, a solution to this problem, aims to lessen the potential ecological consequences of utilising cloud computing for maintaining high performance and dependability. The present article aims to offer insights into the challenges and possibilities in the realm of green cloud computing by summarizing the latest studies and advancements in the field.

With the goal of reducing cloud computing's negative environmental effects, the realm of "green cloud computing" is rapidly growing. In order to do this, Attempts are being undertaken to improve data centre energy usage and reduce cloud computing's carbon footprint. To achieve these goals, a variety of techniques and technologies have been developed, including virtualization, green networking, energy-efficient data centre architectures, and sustainable computing methodologies.

Within academic and professional circles, there has been an increase in interest in green cloud computing over the recent years. Experts have suggested a number of potential remedies and suggested strategies to address the energy consumption and carbon emissions associated with cloud computing. Additionally, businesses are investing in technologies and initiatives aimed at reducing the environmental effects of their data centres as a result of realising the value of environmentally friendly computing.

This article intends to offer a thorough and comprehensive summary of the most recent developments and research in green cloud computing. It encompasses a broad spectrum of subjects, including virtualization techniques, green networks, and ethical computing procedures. Energy-efficient data centre designs are just one example. We also examine the

problems and prospects for green cloud computing and suggest possible directions for future study.

Ultimately, this paper offers insightful observations about the condition of green cloud computing today and its capacity to mitigate its environmental impact. The findings of this paper can guide future research and advancements in this field and provide real-world solutions for organisations and individuals.

II. LITERATURE REVIEW

The Green computing movement has emerged as concerns about the sustainability of the environment have grown.[1]

In recent times, there has been a notable surge in the update of environmentally-friendly cloud computing practices, with numerous studies being done to expand its useful application in various contexts. An energy-saving scheduling algorithm that makes use of a neural network predictor has been created by the authors Truong Duy, Sato, and Inoguchi et al. to lower energy consumption in cloud computing. The algorithm first determines the maximum load by using the server's estimation of the load at time t and the time required to restart.[2]

Effective cloud power management is essential when using green cloud computing, which promotes the use of economical and environmentally friendly technologies. While the cloud offers users all the services they require, it is likely that some of those services won't be fully utilised, which would result in more carbon emissions into the atmosphere and subsequent effect from air pollution. Conducting regular checks to ensure efficient use of resources is imperative.[3]

Some ways to green cloud computing:

The study suggested an "Integrated Green Computing System" to address the problem of carbon emissions brought on by cloud systems in large businesses. This system would include an "Ant Web Algorithm" and a "Special Query Algorithm". The study offers a thorough examination of the environmental effects brought on by the advent of cloud computing. The researchers also looked at how the internet affects people negatively and proposed solutions to lessen the carbon footprint of the internet.[3]

Data centres have experienced substantial growth due to the widespread adoption of cloud computing across various industries. This has increased energy consumption and consequent environmental effects, including a larger carbon footprint. Because energy use and carbon emissions are correlated, energy management strategies that increase cloud computing's energy efficiency are required in order to achieve "green" computing.[4]

This has become a significant problem and challenge for both business and society. Costs and carbon emissions have gone up as a result of the increase in energy consumption. It is crucial to identify an eco-friendly and economically viable solution that effectively tackles the issue of excessive energy usage. The field of cloud computing urgently needs to achieve "green" computing.[4]

Nearby schools have developed a programme to promote eco-friendliness in virtualization and use a variety of strategies to lessen the cradle-to-gate cycle. By taking into account practical options like virtual servers and virtualization preparation and transfer, it illustrates ways to improve system energy efficiency.[5]

Data centres frequently employ virtualization technology because it gives users access to flexible resources while maintaining security and stability. As a result, many data centres are managing their resources through the use of virtualization technology. As a result, many energy-efficient scheduling algorithms have been created especially for virtualized clouds.[6]

Optimising task execution time in data centres requires effective task scheduling. Numerous task scheduling algorithms have been devised, such as Green Round Robin, Random, and Heros. When the results of these algorithms were compared, it was discovered that the Green Cloud scheduling algorithm performed better in terms of energy consumption, with a reduction in power consumption of about 2% when compared to other schedulers.[7]

PUE and DCiE: Data centers employ metrics such as Power Usage Effectiveness (PUE) and Data Center Infrastructure Efficiency (DCiE) to optimize energy consumption and minimize waste. PUE measures the efficiency of energy utilization within data centers, while DCiE serves as a metric for power management and is the reciprocal of PUE.[8]

The acronym "GCA" represents "Green Cloud Architecture," which is a design approach focused on optimising energy usage during cloud computing operations to minimise wasteful

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energy consumption. It puts an emphasis on environmental friendliness by providing eco-friendly services, packages, tools, and prices while reducing energy waste. An interface that offers green products and services and assesses the CO2 emissions of those products and services is referred to as a "green broker." The green approach to cloud computing is viewed as a development that offers hope for environmental preservation in the IT industry.[8]

Users can share resources and services in data centres thanks to virtualization technology, which eliminates the need for pricey on-premises infrastructure. The primary goal of existing solutions is energy efficiency, which is achieved by optimising computing load balancing and lowering the number of deployed computers to support necessary applications. [10]

To achieve their goals and priorities, such as load balancing, response time, revenue maximisation, and electricity usage reduction, cloud users and providers must effectively manage resources. By continuously learning workloads on cloud-based architectures in real-time and enabling seamless resource switching based on configuration changes, machine learning (ML) can be used to improve green cloud resource management. For distributed green cloud servers, it is possible to predict load management and determine the right amount of resources to provision using machine learning (ML). An automated and scalable forecasting framework utilising machine learning (ML) has the potential to predict loading and queuing times, thus enabling the anticipation of future resource needs.[10]

III. DEVELOPMENT MODELS

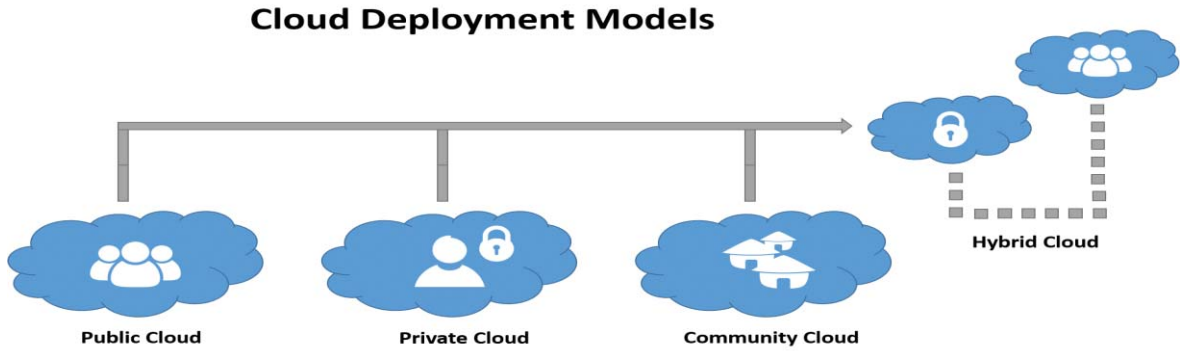

Fig 1. Cloud Deployment Models [16]

a. **Public Cloud:** A type of cloud deployment model called the public cloud offers computing resources, such as hardware and software, to every subscriber. It is

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frequently employed for non-critical applications like file sharing, email services, and the development and testing of software.

b. **Private Cloud**: A private cloud is a type of infrastructure commonly used by businesses, which can be managed internally by the organization or through an external service provider. Unlike public clouds, private clouds are not accessible to the general public and are typically more costly due to the need to purchase and maintain the infrastructure.

c. **Hybrid Cloud:** Organisations use both private and public cloud infrastructure to create a hybrid cloud. When it's necessary to quickly expand IT infrastructure, such as when using public clouds to increase the capacity of private clouds, this model is used. An illustration of this is an online retailer that utilises public clouds to obtain the additional computing power needed to run its web applications during peak periods.

d. **Community Cloud:** Several organisations pool their computing power to create a community cloud. Universities working together on a particular research area and police agencies in a county or state sharing computing resources are two examples of this. Members of the community are typically the only ones with access to its cloud environments.[12]

IV. CLOUD COMPUTING TERMINOLOGIES

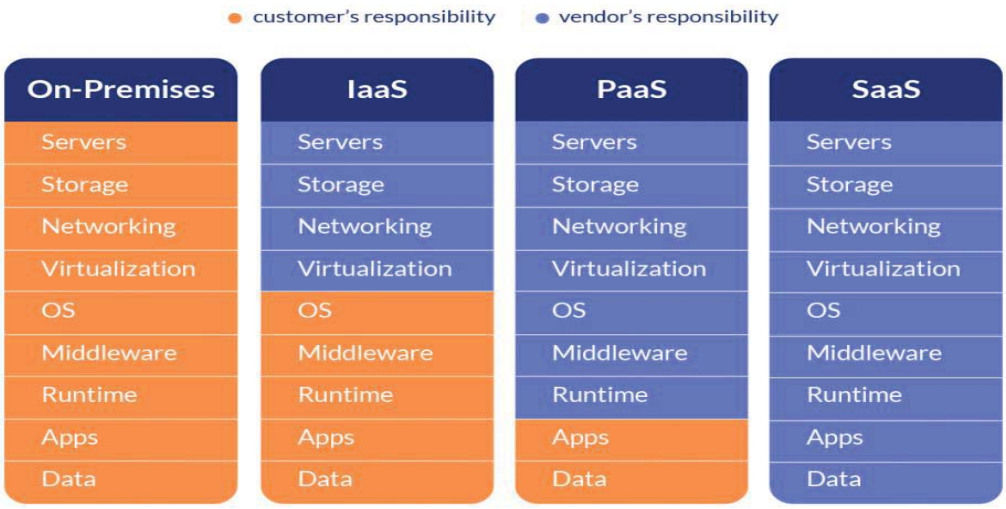

Fig 2. Cloud Computing Categories [15]

a. Infrastructure as a Service (IaaS):

Infrastructure as a Service (IaaS) plays a crucial role in the realm of cloud computing, granting users the ability to leverage essential resources such as network services, virtual or dedicated hardware, and data storage. IaaS exhibits resemblances to traditional IT resources that are well-known to IT departments and developers, providing unparalleled levels of customization and flexibility.

b. Platform as a Service (PaaS):

PaaS (Platform as a Service) is designed to empower organizations by alleviating the burdens of hardware and operating system management, enabling them to focus on seamless application deployment and efficient administration. With PaaS, organizations are freed from labor-intensive tasks such as resource allocation, capacity planning, software maintenance, and patching, allowing them to save time and operate more effectively.

c. Software as a Service (SaaS):

Simply put, Software as a Service (SaaS) delivers a fully-managed and operated product by the service provider. Usually, it's talking about end-user programmes like web-based email. Users only need to concentrate on using the software when using SaaS; they do not need to worry about upkeep or infrastructure management. Users can conveniently send and receive emails without the need to handle email programs, servers, or operating systems, as an example.[11]

d. Backend as a Service (BaaS):

A cloud-based service known as Backend as a Service (BaaS) empowers developers by allowing them to offload intricate technical responsibilities that arise during web or mobile application development, leading to a more streamlined and effective development workflow. This indicates that the front end of the application should be the developers' sole focus. BaaS providers offer ready-made software solutions (for mobile applications) to perform tasks on their servers.

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V. GREEN CLOUD COMPUTING

- **Origin:** As large processing systems like mainframes and peripheral devices grew in popularity in the late 1960s and early 1970s, data centres started to consume a significant amount of electricity. The inception of the Energy Star program by the US Environmental Protection Agency in 1992 marked a significant step towards fostering energy-efficient computing equipment, thereby catalyzing the growing momentum of integrating eco-friendly technologies. However, prior to this, IT vendors had been diligently developing more compact and faster systems for a while. Since then, energy efficiency has also begun to be promoted in many other areas.
- **Definition:** The utilisation of computers and computing devices in a manner that prioritises energy efficiency and environmental sustainability is commonly referred to as 'green computing' or 'green technology'. Incorporating a strategy that focuses on mitigating the adverse environmental impacts of CPUs, servers, peripherals, power systems, and other IT hardware is an integral aspect of utilising these resources. It also places a focus on lowering resource consumption and properly getting rid of e-waste.[12]
- **Features:**

a. Virtualization:

By reducing the number of physical devices needed, virtualization is an important technology that enables the effective use of software and hardware resources. A hypervisor communicates with virtual machines and the underlying hardware to allocate resources in accordance with instructions from the virtual machines, acting as an operating system at the abstraction level. Advanced components such as processors, RAM, routers, discs, switches, and other high-performance hardware are incorporated into cloud systems. Traditional synchronous processing methods may not effectively utilize available resources, potentially leading to certain functions being blocked instead of fully allocating the available resource set before initiating a task. Contrarily, hypervisor-based virtualization removes sequential processing constraints by enabling the execution of multiple tasks concurrently on the same machine while allowing for resource sharing. There are three frequently employed techniques

for generating virtual machines, namely application-based virtualization, operating system-based virtualization, and hypervisor-based virtualization.[13]

b. Consolidation:

Consolidation is the process of combining the data processing of various data centres on a single server using virtual technology. By evenly dividing the workload among the processes, this technique lowers power consumption and conserves energy.[14]

c. Energy Efficient:

Green cloud computing is a technology that saves energy while also helping the environment. It places a strong emphasis on energy conservation and the effective use of power. In the past, processors were inefficient because they used a lot of energy and produced heat. Green cloud computing, on the other hand, addresses this problem and guarantees optimal energy use.[14]

d. Eco-Friendly:

A responsible strategy to reduce the potential environmental effects linked to traditional cloud computing is to adopt eco-friendly practises, such as green cloud computing. It ensures effective resource use by reducing the strain on processors and reusing resources. It also reduces heat and other damaging emissions linked to cloud computing.[14]

- **Need:**

Green cloud computing is crucial for advancing the adoption of eco-friendly technologies and approaches in the IT industry, with the aim of mitigating its detrimental environmental effects and promoting sustainable computing practices. Due to the production of electronic devices, which significantly contributes to the climate and environmental crises by utilising toxic raw materials and energy-intensive processes, the internet has the potential to become one of the most polluting industries. Microchip manufacturing, for example, takes several months to complete and generates a lot of waste relative to the size of the finished product, which exacerbates the issue.

With emissions of 227–270 kilograms of carbon dioxide, recent technologies have increased the environmental impact of producing a single computer. Additionally, the electronic industry uses a lot of water and produces a lot of waste. For instance, The Guardian reported

that in the first three months of 2021, the Intel plant in Ocotillo produced 15,000 metric tons of waste, of which 60% was hazardous. More than 4 million litres of water and 561,000 kilowatt hours of electricity were also used by the plant.

Electronic devices quickly become obsolete, the demand for these products is rising, and it is difficult to properly dispose of their components, all of which make the situation worse. Furthermore, only about 14% of e-waste is properly managed in Europe, suggesting that a sizable portion of it ends up in landfills. A significant amount of e-waste is not properly sorted.

Electricity is consumed in significant amounts when using electronic devices, especially when data is transmitted over the internet. Even though individual usage may not consume much energy, the CO2 emissions produced by the combined energy use of billions of connected devices are comparable to those of a small country.

Given the urgent need to combat climate change, the adoption of environmentally-friendly practices in cloud computing. This problem involves both the availability of energy and pollution. There is a chance that it won't be possible to meet this demand, not just with renewable energy sources, if the demand for energy keeps rising at this rate.

- **How organisations can implement green computing**

1. Putting green computing practises into practise in organisations
2. One method is to choose environmentally friendly cloud storage and backup services.
3. Another is to select certified energy-efficient products, such as those bearing the Energy Star label.
4. It is best to spend your money on durable equipment and to fix or modify broken items rather than throwing them away.
5. When it comes time to get rid of electronic equipment, look for businesses that focus on recycling such items.
6. To prevent unnecessary energy consumption, it is recommended to either enable hibernation or sleep mode on computers during breaks, and power them off when they are not being used.

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7. Since they use less energy than desktop computers, think about switching to laptops and tablets.
8. Digital technology can also aid in the reduction of waste and clutter. For instance, online meetings and remote work can reduce the need for travel and paper when necessary.

VI. ENERGY SAVING TECHNIQUES

S. No	Author	Technique used	Strengths	Virtualization	Tools used
[1]	Kim *et al* (2007) [5]	Optimize power consumption and job deadlines through the utilization of Dynamic Voltage and Frequency Scaling (DVFS).	Both methods of DVS exhibit minimal deterioration in performance over time and result in significant energy savings.	No	GridSim Toolkit
[2]	Kusic *et al* (2009) [6]	Dynamic Voltage and Frequency Scaling (DVFS), Hypervisor-based Virtualization, Resource Consolidation, and Server Power Management	Optimizing energy usage while mitigating performance degradation	Yes	Create their own solution.
]	Buyya *et al* (2010) [7]	Modifying resource allocation and scheduling based on dynamic needs.	The service excellence, optimization of energy usage, customer satisfaction, and eco-friendly resource	Yes	CloudSim

			allocation through Dynamic Voltage and Frequency Scaling (DVFS) are key considerations.		
[4]	Belonglazov and Buyya (2010) [8]	Optimizing the dynamic migration of virtual machines to enhance efficiency, by minimizing the frequency of migration, maximizing the growth potential, utilizing random selection, and implementing DVFS techniques.	Reduce energy usage while fulfilling performance criteria	Yes	CloudSim
[5]	Lago *et al* (2011) [9]	Strategic planning and seamless transition of virtual machines.	Virtual machine scheduling in both federated and non-federated data centers, which are homogeneous or heterogeneous, can be effectively managed by algorithms, leading to enhanced load balancing and energy efficiency.	Yes	CloudSim
[6]	Feller *et al* (2011) [10]	Optimizing the integration of virtual machines with ant	ACO has a notable impact on energy efficiency as it	Yes	Create their own solution.

		colony-inspired algorithms.	enhances server utilization and reduces the need for additional machines.		
[7]	Jang *et al* (2011) [11]	Proposed policies for BCFS and BNF	The measurement of energy usage, scheduling time for virtual machines, and wait time in the running queue are conducted.	Yes	MPSim simulator
[8]	Calheiros *et al* (2011) [12]	Employing Dynamic Voltage and Frequency Scaling (DVFS) techniques to optimize power consumption while ensuring adherence to Service Level Agreements (SLAs).	By adhering to service level agreements (SLAs), it effectively minimizes energy usage.	No	CloudSim Toolkit
[9]	Murtazaev and Oh (2011) [13]	The virtual integration approach employed involves utilizing FF and BF bin packing techniques.	Decreases energy usage in uniform data centers by minimizing server activity.	Yes	Create their own unique simulation toolkit
[10]	Sharma and Sharma (2012) [14]	Algorithm for distributing workload across multiple servers.	An excellent option for conserving resources, cost, and time.	Yes	CloudSim
[11]	Wang *et al*	Enhance the utilization of	Take into account Quality of Service	Yes	CloudSim

	(2012) [15]	resources to their fullest potential.	(QoS)		
[12]	Chen *et al* (2012) [16]	Approach for Modeling and Analyzing Energy Consumption.	The identification of energy consumption and task monitoring in a cloud-based environment, along with the examination of the correlation between system configuration and performance, has aided in the analysis of results that are vital in the development of mechanisms aimed at enhancing energy efficiency.	No	Not implemented
[13]	People *et al* (2012) [17]	Reassignment of tasks and responsibilities.	Minimizing packet loss and utilizing excess server capacity for traffic patterns can enhance efficiency, while selecting a server that matches the desired packet delivery rate and speed can lead to optimization.	No	OPnetand S-2
[14]	People *et al* (2013) [18]	Developing strategies to effectively manage tasks and	Our research revealed a correlation between	No	Java Based dedicated

		responsibilities.	the utilization of servers and the cost of power that followed an exponential trend.		tool
[15]	Ghribi *et al* (2013) [19]	The process of strategizing and relocating virtual machines.	Employing a strategy that integrates linear integer programs with allocation and migration algorithms has the potential to result in notable energy savings, which may vary depending on the system's workload.	Yes	Java based Simulator
[16]	Kord and Haghighi (2013) [20]	In order to attain an optimal trade-off between meeting service level agreements (SLAs) and minimizing power usage, the MCC approach has been implemented.	In order to obtain the necessary data for this algorithm, it is essential to gather information at the hardware level. This includes measuring the overall energy consumption and identifying any violations of the service level agreement (SLA).	Yes	CloudSim toolkit.
[17]	Cao and Zhu (2013) [21]	The scheduling of DAG workflows in EARES-D is accomplished	Implementing this approach can lead to a decrease in energy usage and more	No	CloudSim toolkit.

		through the utilization of DVFS, where the prioritization is based on the workflow's earliest completion time.	efficient utilization of resources.		
[18]	Li *et al* (2013) [22]	One strategy to optimize the allocation of virtual machines is to implement load balancing techniques that distribute physical resources among servers. As part of this approach, it may be necessary to transfer virtual machines to servers that are experiencing higher levels of usage.	According to the analysis performed by the algorithms, it was found that the utilisation of multidimensional resources was well-balanced, resulting in efficient energy conservation.	Yes	CloudSim toolkit.

VII. DISCUSSION AND FINDINGS

The concept of green cloud computing is gaining attention due to increasing concerns about the environmental impact of technology. This relatively new field focuses on reducing energy consumption and carbon emissions associated with the infrastructure and services used in cloud computing. Many studies have been conducted in this field, and some of the major conclusions are presented below:

1. Virtualization: One of the key methods for creating green cloud computing is virtualization. Virtualization allows for the consolidation of multiple physical servers

into a single virtual server, resulting in reduced reliance on physical servers, lower energy consumption, and a decreased carbon footprint associated with physical server usage.

2. Renewable Energy: It is anticipated that more cloud service providers will continue to power their data centres using renewable energy sources. Some cloud companies have already started this trend.
3. Energy-efficient hardware: Employing energy-efficient hardware components is an effective measure to support environmentally-conscious practices in cloud computing. The data centre's cooling requirements are reduced by these hardware components' lower energy and heat production levels.
4. Dynamic resource allocation: To maximise resource utilisation and cut down on energy use, cloud providers can also use dynamic resource allocation methods. This strategy entails distributing resources to fulfil demand and releasing them when they're no longer required.
5. Green certifications: Some cloud service providers have achieved eco-friendly certifications like Leadership in Energy and Environmental Design (LEED) accreditation and Green Grid certification to demonstrate their dedication to sustainable computing.
6. Carbon offsetting: Through funding renewable energy initiatives and acquiring carbon credits, several cloud service providers have begun to offset their carbon emissions. Using this method, the environmental harm caused by cloud computing is intended to be offset.

Further research is necessary to fine-tune energy utilisation and reduce carbon emissions in the realm of environmentally-conscious cloud computing. Viable approaches for achieving environmentally-friendly cloud computing, as indicated by existing research, include virtualization, renewable energy utilisation, energy-efficient hardware implementation, dynamic resource allocation, green certifications, and carbon offsetting

VIII. CONCLUSION

One of the significant advantages of green cloud computing architecture is its capability to maintain real-time performance while consuming less energy compared to conventional internet data centres. Emphasising the importance of environmental protection, green cloud computing promotes responsible production of goods and services that prioritise environmental sustainability. This paper examines the incorporation of green IT characteristics into cloud computing and evaluates the environmental sustainability of cloud services using established standards. Despite the potential for some negative environmental effects, these providers are working to adopt green cloud computing and improve their environmental practices. By adopting this idea, we can develop technology while protecting the environment. Businesses can lower their carbon footprint and improve productivity by utilising green and cloud computing.

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