Green Cloud: Navigating to a SustainableFuture through Green Cloud Computing

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***Abstract*-Green Cloud Computing (GCC) is an innovative technology that has captured increasing attention in recent years due to its limitless possibility to revolutionize the field of sustainable cloud computing and subsequently reduce the impact of cloud computing on the environment. This paper introduces the concept of GCC and discusses its significance in addressing the harmful impact of cloud computing on the environment. It highlights the various approaches used for implementation and the existing work in the field of Green Cloud Computing.It finishes by discussing the hurdles faced and opportunities connected with its implementation.**

Keywords-Cloud Computing, Environmental Protection, Sustainable Data Centers, Renewable Energy, Green Cloud Computing

I. INTRODUCTION

Cloud computing, in recent years, has become a progressively popular means for accessing and utilizing services over the internet. This enables consumers to access applications, data, and storage resources, instantly on demand, without the need for on-premises infrastructure. Cloud computing, in recent years, has emerged as a crucial piece of technology that has enabled both businesses and individuals alike to store and access data online, on the internet. It provides its users with a range of attractive benefits, such as the ability to scale, cost efficiency, and flexibility, making it a desirable option for organizations of all sizes[1]. However, as the demand for cloud computing services continues to grow, so do the energy consumption and environmental impact associated with powering data centers and servers. The IT industry is estimated to be responsible for around 2% of carbon emissions globally, which is nearly equal to the aviation industry[2]. The growth in cloud computing usage is projected to increase this percentage in the coming years[2].

Green Cloud Computing (GCC) has emerged as an innovative technology that moves forward with the goalof minimizingthe impact that Cloud Computing has had on the environment.GCC refers to the practice of designing, developing, including deploying solutions in cloud computing that are energy-efficient and environmentally sustainable.[3] It involves using renewable energy sources, energy-efficient hardware, and data centers

This review document provides a comprehensive review of Green Cloud Computing (GCC), including its definition, importance, environmental impact,approaches, sustainable practices, and case studies. The paper will also examine the challenges and opportunities for sustainable cloud computing, aiming to contribute to the current understanding of GCC and its potential impact on the environment [4].The article is organized as follows: Section 1 delves into the introduction, which discusses the relevance of green cloud and attaining a sustainable future through the use of green cloud technology. Section 2 also discusses the operation of green cloud data centres, while Section 3 discusses the value of green cloud computing and includes a case study. Section 4 discusses the literature review. Furthermore, sections 5 and 6 include case studies, obstacles, and other prospects for embracing green cloud. Finally, a conclusion is added.

II. GREEN CLOUD COMPUTING

GCC, or Green Cloud Computingencompasses the idea ofplanning, designing, and implementingenvironmentally responsible practices inthe operations of cloud computing. This includes the design, deployment, and management of cloud infrastructure that minimizes energy consumption, reduces carbon emissions, and promotes resource efficiency. It also involves the use of renewable energy sources, such as hydroelectric power, solar power, and wind energy, to run data centers and servers. Furthermore, Green Cloud Computing's main objective is to limit e-waste along with promoting recycling and responsible disposal of electronic equipment used in cloud computing[5].In essence, GCC aims to provide cloud computing services that are not only efficient and reliable but also environmentally sustainable [6] [7].

III. IMPORTANCE OF GREEN CLOUD COMPUTING

Sustainable/ Green Cloud Computing is becoming increasingly important due to the environmental impact of cloud computing operations[8].A study conducted by the IEA, or International Energy Agency states that data centers and servers used for cloud computing contribute to global carbon emissions by 2%, which is equivalent to the as much emission generated by the aviation industry[9]. This impact is expected to continue to grow as the demand for cloud computing services increases. Furthermore, it is predicted that data centers globally to become the world's largest energy consumers by 2025 – increasing the ratio of their consumption from 3% in 2017

to 4.5%[10]. Therefore, it's crucial to address the degradative impact that cloud computing has on our environment through sustainable practices.

IV.EXISTING WORK

The existing work on Green Cloud Computing (GCC) has been focused on developing strategies that reduce the total carbon footprint generated by data centers to increase energy efficiency. In order to reduce the detrimental impact that cloud computing has on the environment, energy-efficient hardware, software, and infrastructure solutions are designed and implemented. Some ways in which GCC achieves sustainable cloud infrastructure design:

A. *Virtualization*

It is one of the most studied approaches in existing work.Virtualization is a technique used to partition physical servers into multiple virtual servers, which can improve theefficiency of the total utilization of computing resources, leading to a reduction in energy consumption[11].The use of virtualization technology has been found to reduce energy consumption significantly. Thus, leading to significant savings in cost anda significant reduction in carbon footprint[12]. Virtualization can be implemented using hypervisors or virtual machine managers that partition the physical server into multiple virtual machines[13]. By running multiple virtual machines on a singleserver, the server can be well utilized, reducing the number of physical servers required and associated energy consumption.In addition to reducing energy consumption, virtualization can also improve the flexibility and agility of cloud infrastructure. By enabling virtual machines to be created, moved, and deleted dynamically, cloud service providers can improve resource utilization and reduce waste.

B. *Load Balancing*

Load balancing, in simple terms, is the distribution of workload acrossservers spread across a specific region. This is done in order to improve resource utilization and reduce power consumption. Load balancing algorithms can optimize the use of servers by dynamically allocating resources based on demand, thus reducing the overall need for additional servers and, as a result, lowering energy consumption[14].

C. *Renewable Energy Sources*

The usage of renewable means of energy in cloud computing solidifies itself as a promising approach to successfully reduce the impact of these technologies on the environment. The use of wind, hydro, or solar as a source of renewable energy in power production for cloud infrastructure has resulted in a significant reduction of the carbon footprint of the cloud industry. Along with that, it can help the cloud service providers reduce their dependency on energy sources such as natural gas, coal, and oil, which are significant sources of greenhouse gas emissions. Numerous cloud service providers have already pledged to strategically use of sources of energy that are renewable to power their operations. They have used the following approaches to incorporate sustainable sources of energy in their cloud infrastructure:

Generation of On-site renewable energy: Cloud service providers have the option to install wind turbines, solar panels, or/with other renewable energy sourcesin their data center toproduce electricity. Onsite renewable energy generation can provide a reliable and sustainable source of energy for cloud infrastructure.

Power purchase agreements (PPAs): Cloud service providers have the ability toacquire renewable energy from external suppliersby utilizingPPAs, or power purchase agreements. PPAs can provide access to renewable energy sources at a predictable and stable cost, which can help cloud service providers reduce their operational costs and improve their sustainability[15].

Renewable energy certificates (RECs): Cloud service providers have the option toinvest in renewable energy certificates (RECs) that help them to offset their overall carbon footprint. Renewable Energy Certificates represent the advantages that renewable energy production has for the environment. They can be used to demonstrate a commitment to sustainability [15]. Table 1 as depicted below provides a percentage based ratio of Renewable Energy Usage by reputed cloud service providers.

Table 1: Comparison of renewable energy usage by different cloud providers

Cloud Service Provider	Percentage of Renewable Energy Usage
Amazon Web Service	42%
Microsoft Azure	60%
Google Cloud	100%
IBM Cloud	40%
Sales Force	96%

When compared to traditional energy sources, the initial cost of implementing renewable sources of energy might be on the pricier side, but, the long-term benefits, along with the effective cost savings can be noteworthy. Adopting renewable sources of energy in cloud computing can also help organizations meet their sustainability goals and reduce their carbon footprint. By adopting renewable energy sources, organizations around the globe can showcase their commitment to reducing the damage they do to nature and to readily adopt a more sustainable means of energy[15].

D. *Energy Efficient Hardware*

Energy-efficient hardware involves the use of low-power processors, memory, and storage devices that consume less energy than traditional hardware. This approach can result in significant energy savings, making it a pretty appealing choice for organizations and businesses that are seeking to reduce their carbon footprint[16].

E. *Sustainable Data Centers*

Data centersplay a critical role in cloud infrastructure and have the ability to heavily influence the energy consumption and environmental footprint of cloud service providers. Sustainable data center design and operations can help cloud service providers reduce

their total operational costs while keeping the environment in mind[17].

Sustainable data center design and operations can involve a range of strategies, such as:

Efficient cooling systems: Data centers require cooling systems to prevent servers from overheating. Efficient cooling systems, such as hot aisle/cold aisle configurations and free cooling, can significantly reduce energy consumption and associated costs.

Energy-efficient hardware: Cloud service providers can make use of servers, networking equipment,and storage devices that are energy-efficient,to reduce their energy consumption and improve their sustainability.

Renewable energy sources: As discussed earlier, cloud service providers can make use of renewable energy sources to provide power to their data centers. This will helpthem reduce their reliance on non-renewable energy sources such as coal, oil, gas, etc,and reducing their carbon footprint.

Recycling and waste reduction: Cloud service providers can implement recycling and waste reduction programs to reduce the amount of waste generated by their operations.

Green building design: Cloud service providers can use sustainable building materials, such as recycled materials and low-emission paints, and design buildings to maximize natural light and reduce energy consumption[18].

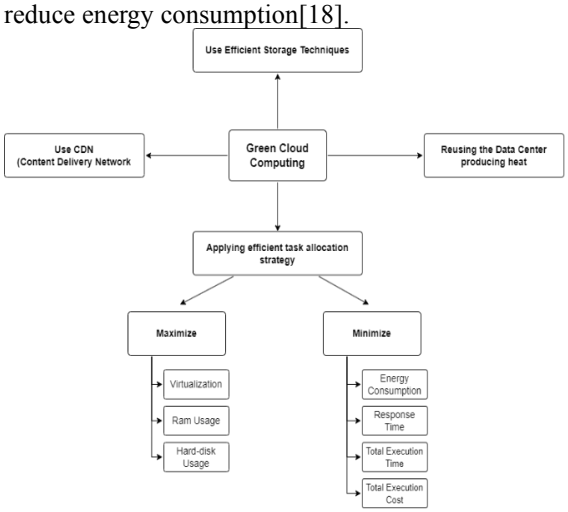

Fig. 1: Visualising how to implement Green Cloud Computing

By implementing sustainable data center design and operations, cloud service providers can significantly reduce their environmental footprint and improve their operational efficiency as shown in Fig. 1. Sustainable data centers can also enhance the resilience and reliability of cloud infrastructure, making it better able to withstand disruptions and outages.

V. CASE STUDIES

Numerous firms have recognized the need for sustainable cloud computing and have devised initiatives to improve their environmental performance and lower their carbon footprint. Table 2 as shown below provides details about the produced carbon footprints with comparison.

Table 2: Comparison of carbon footprint production by different cloud providers

Cloud Service Provider	Carbon Footprint (Metric Ton CO2/Year)
Amazon Web Service	52,000,000
Microsoft Azure	22,000,000
Google Cloud	10,000,000
IBM Cloud	3,000,000
Sales Force	1,000,000

Here are a few examples:

Microsoft: In 2012, Microsoft stated a goal to become carbon neutral by 2030. To reach this goal, Microsoft started by investing in sources of energy that are renewable - wind and solar power are two examples of them.They also introduced energy efficiency techniques in their data centers[19-23].

Apple: Apple has pledged to migrate the power sources used to power its data centersfrom non-renewable energy to 100% renewable energy. They have reached this target in various nations, including the United States and China. Apple has also introduced energy efficiency methods, such as utilizing natural cooling systems and optimizing server utilization, to lower its energy consumption and associated costs. Apple has a goal to run its entire manufacturing chain on 100% renewable energy by 2030[24-27].

EasyJet: EasyJet advertises its passengers with offers of “netzero carbon flights” for every flight operated by them. Investing in offsets that invest in projects that focus on reducing emissions can help achieve the net-zeros offered by the company. The company focuses on being effective by keeping its carbon emissions per passenger kilometer to a maximum of 77 grams using a modern fleet[24], [25], [27].

Volkswagen: Volkswagen in their annual Sustainability Report introduce one of their major agendas - reducing emissions through theimprovement of how efficiently energy is used along with the purchase of carbon offset credits. Volkswagen has established this as an interim goal for 2025.

VI. CHALLENGES AND OPPORTUNITIES

While sustainable cloud computing brings numerous potentials, there are also regulatory and legal obstacles that must be handled. Some of these challenges include:

Data Privacy and Security: As more firms shift their data to the cloud, there is a growing concern about data privacy and security. Businesses must comply with data protection rules and guarantee that their data is secure and protected from cyber-attacks.

Compatibility issues: The implementation of energy-efficient software solutions may not be compatible with existing hardware or software systems, which can create compatibility issues and additional costs.

Dependence on weather: Usage of energy sources that are renewable, like solar or wind power, which are majorly dependent on weather conditions, can lead to problems. Cloudy or calm weather can reduce the amount of energy generated, which can affect the reliability of cloud services[28].

High ImplementationCost: In order to deploy energy-efficient hardware in the existing infrastructure, high

initial investment is required. Renewable energy sources demand upfront costs to install them. These costs can be a barrier to adoption for some organizations[29]-[30].

Despite these challenges,the advantages of Green Cloud Computing are substantial and offer a compelling reason for businesses and organizations to prioritize sustainability. By reducing energy consumption and utilizing renewable energy sources, businesses can increase their profits while also promoting environmentallyfriendly practices that will lead to a more sustainable future.There are substantial chances for enterprises to earn a positive return on investment (ROI) through green cloud computing operations. Some of the potential benefits include:

Reduced Environmental Impact: A notableadvantage of GCC is the reduction in the environmental impact of IT infrastructure. By embracing renewable energy sources, minimizing energy use, and decreasing waste, enabling corporations toreduce their carbon footprints significantly,leading to a much greener and cleaner future[31]-[32].

Cost Saving:Adopting Green Cloud Computing solutions can result in significant cost savings. Energy-efficient hardware and software solutions can reduce energy consumption, translating into lower energy bills. Additionally, using energy sources that are renewable can provide long-term cost savings compared to traditional energy sources.

Positive Brand Image: Implementing Green Cloud Computing can assist in significantly increasing a company's reputation and overall brand image, as it indicates a commitment to environmental sustainability.This can be particularly essential for organizations in industries where environmental sustainability is a primary concern for customers and stakeholders.Customers along with respective stakeholders are becoming more and more conscious of how their company operations are having a detrimental impact on nature and prefer to do business with companies that prioritize sustainability[33]. Fig. 2 explores the different types of initiatives to build green future.

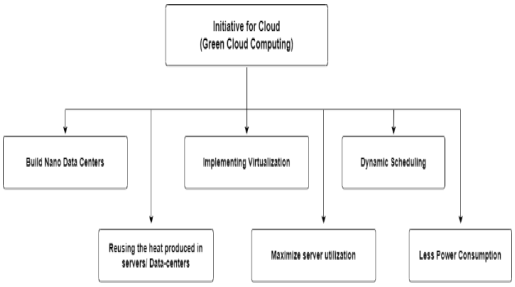

Fig. 2**:** Initiatives to build a future based on Green Cloud Computing

Improved Efficiency: Green Cloud Computing can lead to improved efficiency in data center operations. By optimizing power consumption and resource utilization, businesses can improve the performance and reliability of their cloud services [34].

VII. CONCLUSION

As the globe gets increasingly digitally linked, the need for cloud computing services grows. This, in turn, increases the demand for more energy-efficient and sustainable solutions to power the data centers that supply these services. GCC adoption is critical to meeting these objectives and ensuring the long-term viability of cloud computing. Businesses that adopt sustainable practices can decrease their environmental impact, boost operational efficiency, and demonstrate a commitment to environmental sustainability. GCC research has already resulted in the development of numerous energy-efficient technologies, including low-power processors and virtualization software, which have become industry standards. However, there is still an opportunity for innovation in this field. Collaboration among researchers, governments, and businesses is critical for ensuring that GCC is broadly implemented and has a significant environmental impact.

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