



A Comparative Study of Green Cloud Computing and Traditional Cloud Computing

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Abstract: - The growing popularity of cloud infrastructure has led to a significant rise in energy consumption. 1% of the world's electricity is consumed by data centers contributing significantly to global carbon emission. The pursuit of power has considerably affected the carbon footprint of the environment. The rising energy demand is largely attributed to the rapid expansion of data centers housing hundreds of servers and related infrastructures. This paper emphasizes the need for energy-efficient solutions to mitigate the environmental impact of cloud computing. Our research focused on the concept of Green Cloud Computing (GCC) and the main accomplishments of GCC. Initially, a concise overview of cloud computing is presented. Afterward, the topic of discussion is recent studies and advancements, with a particular focus on environmental issues. Moreover, provide an explanation of the primary aspects of GCC and concentrate on small businesses that face a variety of obstacles when it comes to embracing green cloud computing. Furthermore, elaborate that India's adoption of green cloud computing presents various difficulties. In conclusion, we discuss the future research opportunities in green cloud computing and the unresolved challenges.

Keywords: - Cloud Computing, Green Cloud Computing, energy efficiency, Carbon emission

I. INTRODUCTION

In today's world, organizations of all sizes, from multinational corporations to startups, are embracing Cloud Computing, and many are still transitioning to it due to its ability to reduce costs, lower maintenance requirements, and increase data capacity through servers managed by cloud service providers.

Cloud computing involves saving and retrieving data and applications on distant servers available via the internet, rather than on the hard drive of a computer or a local server. Often referred to as Internet-based computing, this technology offers resources as a service over the Internet to users. The information stored can include files, images, documents, or any other type of storable items.

A. Origin of Cloud Computing

Mainframe computing from the 1950s and the internet boom of the 1990s merged to pave the way for cloud computing. Following the introduction of web-based services by companies like Amazon, Google, and Salesforce in the early 2000s, the term "cloud computing" has become widely recognized. The concept provides on-demand internet access to computational resources, which supports scalability, flexibility, and cost efficiency [1].

Today, cloud computing is ubiquitous, powering a variety of services across different sectors and revolutionizing how data is processed, stored, and retrieved.

B. Architecture of Cloud Computing [1]

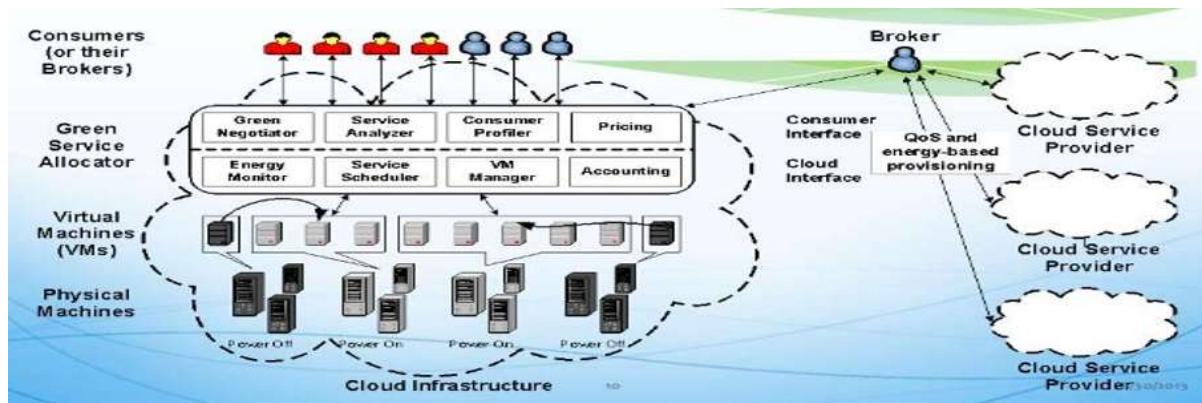


Fig.1 Architecture of Cloud Computing

- **Consumers / Brokers:** They can submit service requests from any location worldwide to the cloud. It is crucial to understand that there may be a distinction between cloud consumers and users of the services offered. For example, a consumer could be a business that is launching a web application, which experiences fluctuating workloads depending on the number of users accessing it.
- **Green Resource Allocator:** This functions as the intermediary between the cloud infrastructures and its users. It needs to facilitate interactions to promote energy-efficient resource management.
- **Virtual Machines:** These can be initiated and terminated dynamically on a physical machine in response to incoming requests, thereby offering optimal flexibility in allocating various resource partitions on the same physical machine to cater to specific service requirements [1].
- **Physical Machine:** It generates virtualized resources to fulfill service demands by supplying the hardware infrastructure of the underlying physical computing servers.

II. GREEN CLOUD COMPUTING [6]

Green cloud computing focuses on creating environmentally sustainable cloud infrastructure and services by minimizing their ecological impact through strategies such as energy efficiency and the incorporation of renewable energy sources. Its objective is to reduce the carbon footprint associated with data centers and cloud operations, covering all aspects from hardware to software.

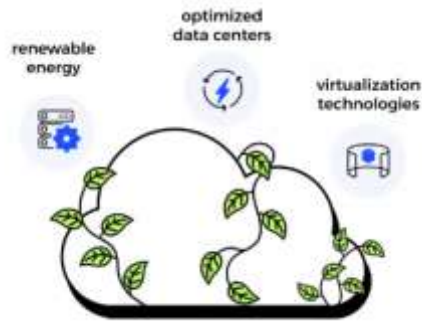


Fig.2 Green Cloud Computing

A. The Evolution of Green Cloud Computing [4]

The inception of green cloud computing can be traced back to the early 1990s, when the U.S. Environmental Protection Agency (EPA) initiated the Energy Star program aimed at encouraging the use of energy-efficient electronics. This initiative established a foundation for sustainable information technology. In the 2000s, the expansion of data centers raised concerns regarding their substantial energy consumption, prompting initial endeavors to enhance computing efficiency.

Early Developments (1990s – 2000s):

- **Energy Star & IT Efficiency:** The Energy Star initiative has encouraged the development of energy-efficient IT equipment, prompting manufacturers to create devices that consume less power.
- **Virtualization & Consolidation:** During the 2000s, virtualization technologies such as VMware facilitated the operation of multiple workloads on a reduced number of physical servers, thereby decreasing power usage and cooling requirements.

The Rise of Sustainable Cloud Computing (2010s):

- **Hyperscale Data Centers:** Major cloud service providers, including AWS, Google Cloud, and Microsoft Azure, have initiated the construction of extensive, energy-efficient data centers. They have implemented advancements such as liquid cooling systems and smart workload management.
- **Renewable Energy Integration:** Leading technology companies have pledged to utilize 100% renewable energy, resulting in significant investments in solar and wind energy to mitigate emissions from data centers.

Modern Innovations (2020s – Present):

- **Carbon-Aware Computing:** Cloud service providers are increasingly utilizing AI-based workload scheduling to execute tasks during periods of low carbon emissions, thereby decreasing their overall carbon footprint.
- **Heat Reuse & Alternative Cooling:** Data centers are strategically situated in cooler climates or employ innovative cooling methods for adjacent structures, including seawater cooling and heat recovery systems.

- **Sustainability Metrics & Transparency:** Solutions such as 'Google Cloud's Carbon Footprint' enable organizations to monitor and reduce their carbon impact associated with cloud services.

B. Key aspects of Green Cloud Computing:

- ❖ **Energy Efficiency:** This includes using energy-efficient hardware (servers, cooling systems, etc.), optimizing power consumption, and implementing dynamic power management to shut down idle resources.
- ❖ **Renewable Energy:** Utilizing renewable energy sources like solar, wind, and hydro power to power data centers reduces reliance on fossil fuels.
- ❖ **Virtualization:** Server virtualization enables the operation of several virtual machines on a single physical server, thereby minimizing the requirement for physical hardware and the related energy usage.
- ❖ **Cooling Solutions:** Employing efficient cooling methods, such as liquid cooling or cold-plate cooling, minimizes energy waste from cooling systems.

C. Benefits of Green Cloud Computing [6]

- **Optimized energy consumption:** Cloud computing, especially green cloud computing, provides a significantly more energy-efficient solution compared to traditional on-premises data centers, which are notorious for their high power consumption. By moving their IT infrastructure to the cloud and implementing sustainable cloud computing practices, organizations can achieve significant energy savings. An analysis by Accenture of leading public cloud service providers shows that transitioning from on-premises systems to the cloud can lead to a remarkable 65% decrease in energy consumption.
- **Reduced carbon footprint:** Through the enhancement of energy efficiency and the adoption of renewable energy sources, green cloud computing plays a significant role in lowering carbon emissions. According to Accenture's report titled 'The Green Behind the Cloud', transitioning to public cloud services can lead to a reduction of global carbon emissions by 84%, equating to 59 million tons of CO₂ annually. This reduction corresponds to a 5.9% decrease in overall IT emissions, which is comparable to removing 22 million vehicles from the roads. Additionally, developing software applications tailored for the cloud can achieve a carbon emissions reduction of up to 98%.



Fig 3. Benefits of Green Cloud Computing [6]

- **Reduced Cost efficiency:** Utilizing green cloud computing not only enables organizations to decrease energy usage, lower carbon emissions, and promote environmental sustainability, but it can also result in significant cost savings—ranging from reduced energy expenses for cloud providers to lower cloud service costs for users.
- **Improved brand image:** In addition to the immediate environmental advantages of enhanced energy efficiency and lower carbon emissions, implementing green computing practices can yield further indirect benefits. By visibly committing to environmental stewardship through green cloud computing, your organization fosters a more favorable perception among clients and stakeholders, thereby enhancing your brand image in a time when environmental issues and the demand for sustainability are increasingly prominent.

D. Green Cloud Computing Roadmap [5]: Implementing Sustainable Practices

Businesses can take several essential steps to adopt green cloud practices and minimize their environmental footprint while enhancing operational efficiency.

- ❖ **Assess your current data setup and understand its energy consumption:** Evaluate your existing configuration to pinpoint areas of inefficiency in energy usage and emissions. Recognize obsolete equipment and systems that require modernization to enhance energy efficiency.
- ❖ **Select a Green Cloud Provider:** Select cloud service providers that demonstrate robust sustainability initiatives. Prioritize those utilizing renewable energy sources and operating efficient data centers, and seek certifications such as LEED to validate their environmentally friendly practices.
- ❖ **Adopt Energy-Efficient Technologies:** Adopt virtualization and containerization techniques to streamline workloads and decrease energy consumption. Explore serverless computing to enhance resource efficiency and lower energy waste during idle periods.
- ❖ **Train Employees:** Provide education on sustainable practices to employees. Promote energy-efficient habits and instruct them on how their actions can minimize the company's carbon footprint.
- ❖ **Optimize Workflows:** Implement tools such as auto-scaling to modify resource distribution according to demand, thereby promoting effective energy utilization and preventing over-provisioning.
- ❖ **Monitor Progress:** Regularly monitor energy usage and emissions through cloud-based tools. Modify strategies according to real-time data to enhance efficiency progressively.

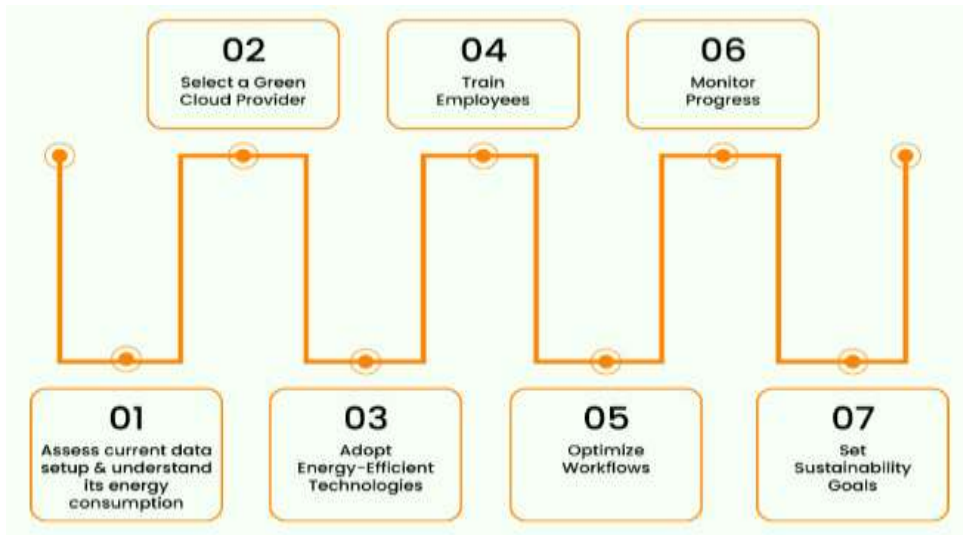


Fig.4 Green Cloud Computing Roadmap

- ❖ **Set Sustainability Goals:** Establish clear and quantifiable sustainability objectives, such as reducing carbon emissions by a defined percentage. Consistently evaluate and update these goals to guarantee ongoing advancement.

III. ADOPTING RENEWABLE ENERGY AT DATA CENTERS

Data centers can choose from various methods to acquire renewable energy or establish their own onsite facilities.

- ❖ **Solar power [9]:** Data center executives aiming to increase their solar energy usage have several options: they can install solar panels on building rooftops, establish a solar farm, or acquire solar power from a utility provider. By 2050, the electric power industry is projected to account for 78% of the solar power supply. However, solar energy generation is contingent upon sunlight availability, which restricts its effectiveness unless integrated with Battery Energy Storage System (BESS) technology for energy capture and storage. Furthermore, substantial installations are necessary to produce adequate energy for data center operations. Nevertheless, advancements in battery storage technology will facilitate large-scale energy capture and storage in the future. Data center managers anticipate that by 2025, 13% of their energy will be sourced from solar power. Meta has officially announced a solar initiative with a capacity of 720 megawatts, in partnership with the energy producer Silicon Ranch, which includes seven projects located in Georgia and Tennessee.

How Is Energy Used in the U.S.?

According to the **Ember's Yearly Electricity Data Report**, U.S. utility-scale electricity generation by source and share of total in 2024

FOSSIL FUELS		RENEWABLES	
POWER SOURCES	SHARE OF TOTAL	POWER SOURCES	SHARE OF TOTAL
Natural Gas	42.5%	Wind	10.3%
Coal	14.9%	Hydropower	5.4%
Nuclear Energy	17.8%	Solar	6.9%
Other Fossil	0.7%	Biomass	1.1%

Table.1 Comparison of Fossil Fuels and Renewable Sources

- ❖ **Wind power:** Wind energy is generated by large turbines, which are generally situated offshore or in sparsely populated regions due to their aesthetic impact. Despite their unappealing appearance, the abundance of wind and the declining costs associated with this technology render it a viable option for data centers and various enterprises. Operators of data centers anticipate that by 2026, wind energy will fulfill eight percent of their energy requirements. Companies like Google are already utilizing wind power at their data centers located in Chile and Finland. In the year 2024, wind and solar energy together contributed a historic 17% (757 TWh) of the total electricity generated in the United States, marking a 15% increase (+97 TWh) compared to 2023. adequate to provide electricity for an extra 9.2 million homes. Concurrently, coal production has reached its lowest point in history, contributing merely 15% to the total electricity generation in the US. In 2024, California and Nevada led the nation in solar power, becoming the first states to surpass 30% annual solar share, with California hitting 32% and Nevada 31% – the highest shares of any state.

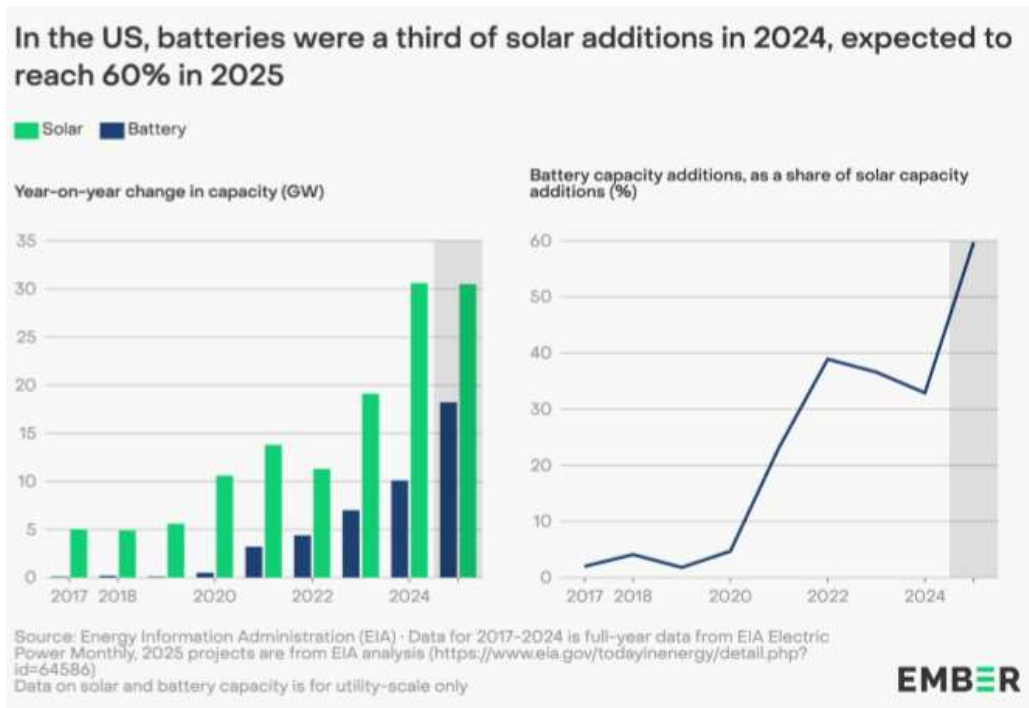


Fig.5 Data on Solar and battery capacity is for utility scale

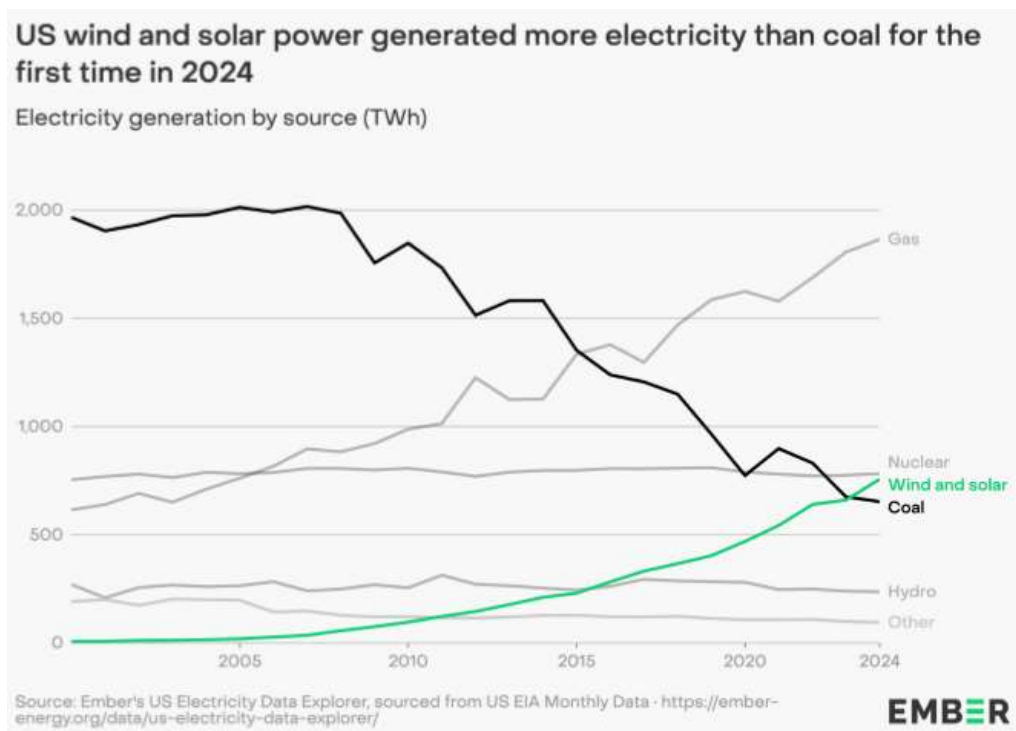


Fig.6 Electricity generation by wind and solar

❖ **Geothermal energy [9]:** Geothermal energy is obtained from the hot water located beneath the Earth's surface. It is an economical and renewable energy source that requires significantly less land compared to solar and wind energy systems. Nevertheless, the process of drilling these wells demands considerable resources. Google, in collaboration with the startup Fervo, is working on a geothermal power initiative in Nevada aimed at delivering a continuous, carbon-free energy supply to support the state's electrical grid.

- ❖ **Hydroelectric power:** Data centers situated in proximity to hydroelectric power facilities leverage water resources, including rivers, lakes, and waterfalls, for powering and cooling their equipment. Data Center Light, based in Linthal, Switzerland, operates its own hydropower plant, utilizing 99.1% hydropower, while the remaining 0.1% is derived from solar energy.
- ❖ **Biomass energy:** Biomass energy is generated through the combustion of recently living organisms, including wood, agricultural residues, and organic waste, to produce energy. Although currently a specialized application, data centers are investigating the potential for broader use of biomass energy. Apple is collaborating with Aarhus University to harness biomass energy for its data center located in Viborg, Denmark.

IV. GREEN CLOUD COMPUTING IN REAL LIFE

In this section, we examine the leading enterprises based in the GCC that provide green hosting services globally. Across 26 countries, there are a total of 342 green hosting companies. According to Buycpanel, adopting Green Web Hosting is not only beneficial for the environment but also one of the most effective methods to minimize carbon footprints. Additional benefits include energy efficiency, certification, utilization of renewable energy sources, cost savings, shared hosting, reduction of e-waste, and adherence to protocols. The foremost companies in this sector include A2 Hosting, SiteGround, InMotion, DreamHost, iPage, HostPapa, GreenGeeks, and Fat Cow.

According to the Green Hosting Report, the Netherlands leads in this sector with 150 companies, followed by Germany in second place with 49 companies. The United Kingdom and the United States are tied for third place, each having 28 companies. Switzerland ranks fourth with 13 companies, while Belgium occupies the fifth position with 10 companies.

- **Greengeeks [3]**, to replace the energy they consume, they buy wind energy credits. They buy three times as much renewable energy as their servers consume and return it to the grid. When you use GreenGeeks, your website becomes carbon neutral or negative. For every customer who signs up for their web hosting service, they also plant a tree. GreenGeeks does not necessitate any technical expertise. They have a one-click WordPress setup feature as well as a user-friendly onboarding process.
- **Kualo Green Hosting [3]** comes in second. They are also an EPA Green Power Partner and run entirely on renewable energy. They've invested in energy-efficient servers and are transparent about their green business practices (they are a completely paperless company and their employees are encouraged to work remotely to avoid unnecessary travel and commuting).
- **DreamHost**, to provide a green web hosting solution, they utilize a holistic approach. It has assessed and quantified their environmental effect, taking into account the energy required to power and cool their servers as well as the energy efficiency of their premises. They've even looked into the impact of their employees' commutes and made changes to their procedures as a result. Grids that collect energy from renewable sources are used to power DreamHost's servers, as per the website.
- **HostPaPa [3]** was among the pioneering web hosting companies to commit to environmental sustainability, as stated on their website. They purchase green energy certificates to compensate for the

electricity consumed by their servers and offices. Additionally, HostPaPa offers green credentials and banners that can be displayed on your website to demonstrate your commitment to eco-friendliness. Although HostPaPa utilizes renewable energy, it is positioned in fourth place due to its elevated pricing and limited unlimited features. Moreover, their green credentials and banners lack the polished and professional appearance found in those of GreenGeeks. While they are distinctive and provide some value, they do not match the high standards of design and expertise exhibited by GreenGeeks.

V. ADOPTING GREEN CLOUD COMPUTING CAN BE CHALLENGING FOR SMALL BUSINESSES

Small businesses face several hurdles when adopting green cloud computing, including high initial costs, the need for specialized expertise, limited awareness of the benefits, and the difficulty of finding suitable green cloud providers. Additionally, regulatory variations and the complexity of measuring environmental impact can also pose challenges.

Here's a detailed examination of the challenges:

1. High Initial Costs:

- **Initial Capital Expenditure:** Green cloud computing necessitates a substantial initial investment in energy-efficient infrastructure, renewable energy sources, and possible enhancements to current hardware.
- **Financial Barrier:** These costs can be a significant barrier for small and medium-sized enterprises (SMEs) that may have limited budgets.

2. Technological Barriers:

- **Expertise Required:** Implementing green cloud solutions, especially those utilizing technologies like AI for energy optimization, requires specialized expertise.
- **Lack of In-House Skills:** Many companies lack the in-house skills to properly implement and manage these sophisticated systems.

3. Limited Awareness:

- **Insufficient Awareness:** Numerous companies do not completely recognize the environmental and economic advantages associated with green cloud computing.
- **Resistance to Change:** This lack of awareness can lead to resistance to adopting sustainable alternatives.

4. Cloud Provider Dependency:

- **Limited Options:** Not all cloud service providers offer robust green cloud solutions, limiting the choices for businesses.
- **Finding Suitable Providers:** Identifying and selecting a provider that aligns with a business's sustainable cloud infrastructure goals can be challenging.

Opportunities for Small Businesses

In spite of these obstacles, small enterprises can gain advantages from GCC by:

- **Reducing Energy Costs:** Implementing energy-efficient practices can help small businesses reduce their energy costs and improve their bottom line.
- **Enhancing Brand Reputation:** Adopting sustainable practices can enhance a small business's brand reputation and appeal to environmentally conscious customers.
- **Accessing Cloud Services:** Small businesses can leverage cloud services that offer GCC solutions, reducing the need for upfront investments in infrastructure.

By addressing these challenges and opportunities, small businesses in India can benefit from adopting GCC practices and contribute to a more sustainable future.

VI. INDIA'S ADOPTION OF GREEN CLOUD COMPUTING POSES VARIOUS CHALLENGES

Including high initial costs, lack of awareness and skilled personnel, security concerns, and data sovereignty issues. Additionally, the need for energy-efficient hardware and renewable energy sources, along with the complexities of integrating green technologies into existing cloud infrastructure, pose hurdles.

❖ High Initial Costs:

- Shifting to green cloud computing requires substantial initial investments in energy-efficient hardware, the integration of renewable energy sources, and enhancements to existing infrastructure.
- These costs can be a barrier for many businesses, especially small and medium-sized enterprises (SMEs).

❖ Lack of Awareness and Skilled Manpower:

- There's a need for greater awareness among businesses and consumers about the benefits of green computing and its potential to reduce environmental impact.
- There is a deficiency of qualified individuals possessing knowledge in green cloud computing technologies and methodologies.

❖ Security and Privacy Concerns:

- Data security and privacy remain significant concerns when storing data in the cloud, particularly with green cloud solutions.
- Organizations must establish strong security measures and adhere to applicable regulations.

❖ Data Sovereignty and Compliance:

- India has specific data localization regulations, which can complicate the adoption of green cloud computing, especially when relying on international cloud providers.
- Ensuring compliance with these regulations and maintaining data sovereignty within India's borders can be a challenge.

❖ Infrastructure and Technological Challenges:

- Upgrading existing IT infrastructure to support green cloud computing can be complex and involve challenges in integrating new technologies.
- The need for energy-efficient hardware and the use of renewable energy sources also require specialized expertise.

❖ Resource Allocation and Optimization:

- Efficiently allocating and utilizing cloud resources is crucial for reducing energy consumption and minimizing environmental impact.
- Developing algorithms and techniques for dynamic resource allocation based on energy availability is a key challenge.

❖ Vendor Management and Integration:

- Managing relationships with cloud service providers and ensuring that they align with green cloud computing principles can be challenging.
- Integrating green technologies into existing multi-cloud environments also adds to the complexity.

VII. CONCLUSION

While traditional cloud computing offers significant benefits like cost savings and scalability, Green Cloud Computing presents a crucial path towards sustainability by significantly reducing energy consumption and carbon emissions. Green Cloud utilizes energy-efficient hardware, virtualization, and renewable energy sources to minimize environmental impact while still enabling efficient and reliable IT operations. Green Cloud Computing offers a compelling solution for achieving both technological and environmental sustainability. While traditional cloud computing has its advantages, its impact on the environment is a growing concern. Organizations should consider adopting green cloud strategies to reduce their carbon footprint and contribute to a more sustainable future.

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