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Green Cloud Computing: Goals, Techniques, Architectures, and Research Challenges

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***Abstract*—Customers from all around the world may access processing power and resources through cloud computing. It offers excellent performance and cost savings compared to specialized high-performance computing equipment. However, this service necessitates enormous data centers, which use a lot of energy and generate a lot of CO_2. Green cloud computing is created to solve this problem by using recycled energy to cut down on energy use and CO_2 emissions. The motivation behind choosing Green Cloud is committed to developing environmentally sound, resource-efficient, low-carbon-emitting, and recyclable solutions. Green computing research focuses on creating effective clouds with environmentally friendly features including power management, virtualization, high-performance computing, load balancing, green data centers, reusability, and recyclability. Providing Quality Of Service to end users while also achieving green computing for computing systems, attaining energy-efficiency control, and meeting a performance guarantee have all become essential concerns for cloud providers. In this paper, the different architectures of green cloud computing are surveyed. The methodology includes the identification of techniques to make the cloud 'green'. Further, the goals and research challenges of green cloud computing are explored. This research provides a state-of-art about the green cloud for the researchers.**

***Keywords*—Green Cloud Computing, Cloud Computing, high-performance computing, virtualization.**

I. Introduction

Cloud computing is a method of utilizing resources (computing resources) over the internet instead of relying on local servers or individual devices to run applications. This technology allows users to access services whenever needed and to scale the allocated resources up or down based on their requirements. Computing is done on virtual servers, giving users more flexibility and cost-efficiency.

Analogous to the National Institute of Standards and Technology [1], cloud computing furnishes customers with services, including Infrastructure as a Service, Platform as a Service, and Software as a Service. to entice business application owners to adopt and migrate their applications to the cloud (as shown in Figure 1).

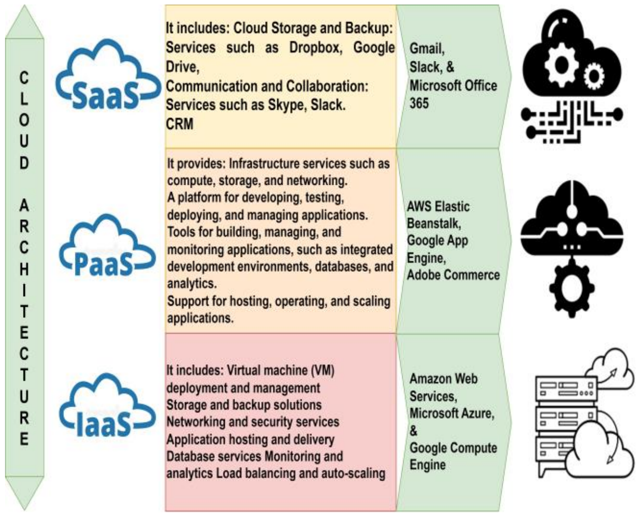

Fig 1.- Cloud Computing Service Layers Architecture [1]

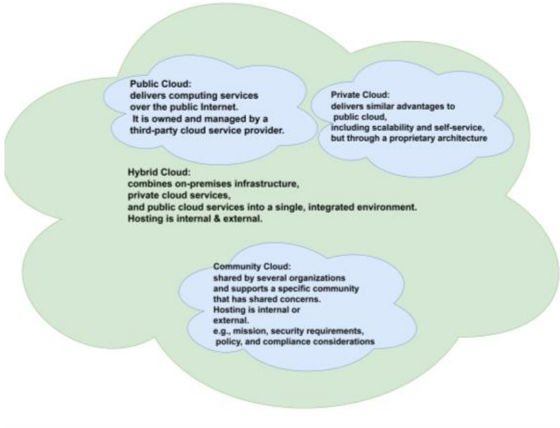

Fig 2. - Cloud Deployment Methods [2]

NIST also accentuates four deployment methods (for sharing the computer infrastructure that provides these services): private, community, public, and hybrid cloud (as shown in Fig. 2).

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Green Cloud Computing is a novel computing paradigm that pares down on heightened energy efficiency and streamlines cloud computing applications and services. It attempts to lessen the energy usage of cloud resources and the associated carbon footprint while boosting overall cloud performance. To minimize energy usage, it carries out techniques such as virtualization, resource scheduling, power management, and data center consolidation. Additionally, Green Cloud Computing encourages the utilization of renewable energy sources, effective cooling, and other environmentally conscious approaches such as cost stockpile, Increased Storage Capacity, Automation of IT Management, Improved Mobility, Amplified Security, Improved Disaster Recuperation, Efficiency is heightened to reduction the environmental impact of cloud computing services [2].

Goals and techniques: Green cloud computing architecture aims to decrease the use of hazardous chemicals, improve a product's lifetime energy efficiency, and encourage the recyclable or biodegradable disposal of production waste[3]. The use of computers as efficiently as feasible in terms of energy use, as well as the development of frameworks and algorithms for performance-related computing breakthroughs, are major areas that researchers are still looking into. Product lifetime, algorithmic effectiveness, virtualization, resource allocation, and power management are a few strategies for green computing. Table 1 shows the different methods like nano data centers, DVDS, and virtualization to turn the Cloud "Green" [4].

Table 1: Various Techniques to Make the Cloud "Green"[4]

S. No.	Techniques	
	Terms	***Explanation***
1.	Nano data centers :	Nano Data Centers are a new type of distributed data center designed to be small-scale and deployed quickly and easily in close physical proximity to the data source or application they are supporting. They offer advantages such as reduced latency, improved data security, and cost-effectiveness due to lower power and cooling requirements.
2.	DVDS:	It is a process that allows cloud providers to calibrate the voltage and frequency of the processor stemming from the workload supremacy needs of the system. By doing so, it enables them to better manage power consumption and performance of the server, thus leading to cost savings and improved efficiency.
3.	Utilizing Virtual ization:	Systems resources are increased in an environmentally friendly manner. The server group can maximize resource sharing since it makes monitoring and resource management easier [5].

II. The Efficiency of Data Centres and Virtualization of Servers

Companies using cloud computing must be conscious of their responsibility to the environment. IT, manufacturing, and business analysis companies now understand that they must take steps to reduce their environmental impact. To achieve green computing, processors in data centers must be cooled, which requires a cooling system and consumes electricity. To make this process more efficient, energy-efficient systems can be used and virtualization of servers can be employed [6]. By virtualizing servers, a physical server can be split into several virtual servers, which can run simultaneously.

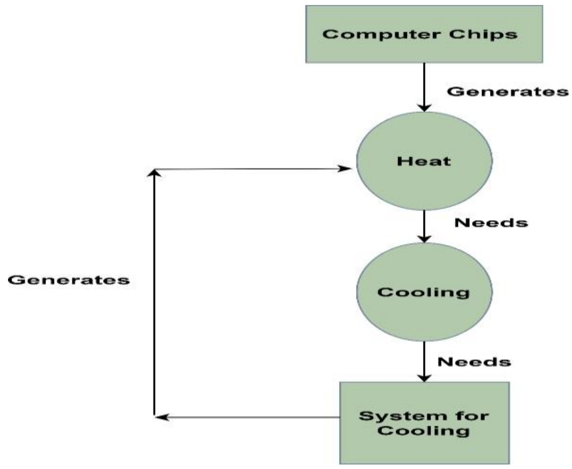

Fig 3. Heat Generation Cycle [5]

Green computing has so far been accomplished via several different methods, including VM consolidation, virtualization of servers, DVFC, live relocation, and resource trading. The most popular ones among them are VM consolidation, server virtualization, and DVFS[4]. Table 2 covers all methodology and findings of the methods suggested for ameliorating the energy efficiency of data centers & virtual machines.

Table 2: Various Procedures Suggested by Earlier Writers to Improve Energy Efficiency

S. No.	Various regimens make cloud computing more energy-efficient.		
	Authors	***Methodology***	***Findings***
1.	Deng, Xiang [7]	Eco-power Algorithm	It is used to diminish the outlay of eco-wave power.
2.	Arthi T, Shahul Hameed H [8]	Automatic Virtual Machine migration	Economical Efficiency.
3.	S. Usmin, M. Arockia Irudayaraja. [9]	EVISBP	It is used to cut back the number of servers used.
4.	Muhammad Anan, Nidal Naseer [10]	DMA	To shrink the CO_2 outpouring
5.	Fahimeh Farahnakian, Pasi Liljeberg [11]	3-Level hierarchical Virtual Machine consolidation	To subsume energy consumed
6.	Marta Chinnici, Andrea Quintiliani [12]	Substitute of components with amplified energy-efficient once.	Scrutinize the DC's energy saving

The study in [table2] is comprehensive and covers all methodology and findings of the methods suggested for ameliorating the energy efficiency of data centers & virtual machines.

The call for cloud computing has led to a growth in data centers which require optimization to be energy efficient. Server virtualization has been implemented and has resulted in reduced energy consumption. Reducing the CO_2 footprint in the environment is of great concern and further research should be done to explore other resources such as networks and storage that support the power consumption of a cloud.[13]

III. Architecture for Energy Management

This architecture proposes a model of cloud computing that focuses on sustainability and energy efficiency. It takes the benefits of renewable energy sources to power cloud services and employs virtual machines to deliver applications and services. Resource allocation algorithms and techniques are used to minimize energy consumption while maintaining the same quality of service (as shown in Fig 4). Additionally, the architecture incorporates features to ensure data security and privacy. Adopting this model promises businesses to cost savings, improved efficiency, and greater sustainability.

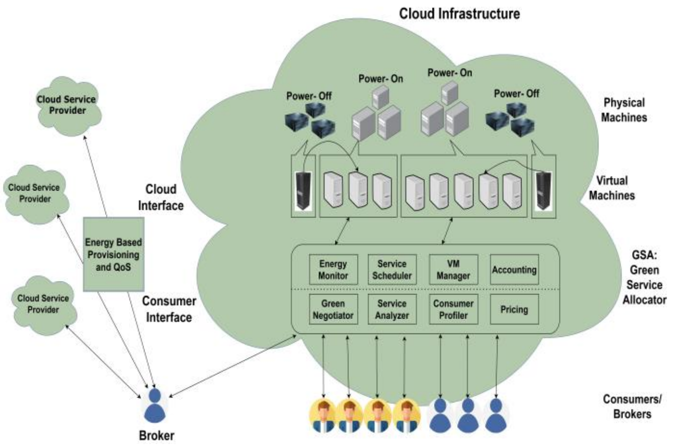

Fig 4. Green Cloud Computing Architecture with Efficient Resource Allocation [14]

A green service allocator is an intelligent algorithm used in green cloud computing architectures to allocate services and resources to reduce energy expenditure. The allocator is responsible for finding the prevailing energy-efficient way to distribute and allocate tasks and resources among servers in the cloud.

Virtual machines- situated on servers that are energized by renewable energy sources are kept. Virtual machines provide the same services as physical machines, but require less energy and cost less to operate. Furthermore, virtual machines are more efficient in terms of resource utilization, as they can be utilized and released quickly and easily, depending on the user's needs.

Physical machines- can include servers, storage devices, networking equipment, and other components. These physical machines are responsible for providing computing resources to users and applications that access the cloud. Green cloud computing architecture utilizes energy-efficient methods to shrink power utilization rates and improve the overall proficiency of the cloud.

Cloud Service Provider: Green Cloud Technologies is a cloud service provider that uses a green cloud computing architecture. Their cloud platform combines proprietary technology and advanced analytics to reduce energy consumption and improve performance. Green Cloud offers cloud solutions for companies of all sizes, from small businesses to large enterprises. Their services include cloud storage, cloud computing, virtualization, and disaster recovery. Table 3 shows the merits and demerits of Energy Management Architecture.

Table 3: Merits and Demerits of Architecture [14]

S. No.	Merits and Demerits of Architecture	
	Merits	***Demerits***
1.	Minimizes the amount of hardware and physical space needed to keep data, increasing energy efficiency.	Scalability is limited: This architecture is limited in its ability to scale up the number of users and services because it is based on cloud computing.
2.	This architecture offers a scalable solution for organizations to efficiently manage their energy needs. Hence improves analytics.	Security risk is always a concern because this architecture is dealing with cloud computing and energy management
3.	Automated sensors are used by organizations to monitor their energy usage more accurately and efficiently. It detects changes in energy consumption and alerts them when usage is higher than expected.	Energy management can b e costly due to the expense s associated with the neces sary hardware, software, an d services to ensure the sys tem is functioning correctl y.

Main models for energy management: static and dynamic.

A. Static Architecture Energy Management: It concentrates on modernizing computing clouds by utilizing low-power components and maintaining a tolerable degree of performance in the system. Low-power alternatives include mobile and handheld devices, which can be used with the majority of cloud computing platforms. The Central Processing Unit typically expends the majority of the power for a node of a cloud, making it the most energy-demanding component in the system. Additionally, memory modules use a lot of energy. Cloud systems can be built with low-power CPUs and memory components to allow energy-aware static management. These systems, which are made up of low-power modules, include Green Destiny[14] and IBM Blue Gene/L[15] as examples. Due to their significant proportion in system power, CPUs and memory banks are the primary subjects of research in power-aware technologies. Table 4 shows some of the merits and demerits of static architecture for energy management [SAEM].

Table 4: Merits and Demerits of SAEM[15]

S. No.	Merits and Demerits of SAEM	
	Merits	***Demerits***
1.	Because system components don't need to be provisioned or reconfigured, static architecture is energy-efficient.	As it depends on pre-defined servers, storage, and other processing resources, scaling up or down is challenging.
2.	Since the number of components is fixed in static design, cloud restore sources can be scaled more easily.	It is challenging to meet unexpected shifts in workloads and resource requirements.
3.	As there is no reconfiguration or modification of the components, the static design enhances the dependability of the cloud system.	Because it only uses static settings, energy usage is difficult to improve.

B. Dynamic Architecture Energy Management (DAM): DAM is a collection of strategies that makes it easier for cloud systems to react in real-time to changing materials needs and other dynamic cloud system situations [16]. Table

5 shows some of the merits and demerits of Dynamic architecture for energy management [DAEM].

Table 5: Merits and Demerits of DAEM [16]

S. No.	Merits and Demerits of DAEM	
	Merits	*Demerits*
1.	Enhancing computer environments for energy efficiency and lowering energy-related expenditures, may assist enterprises in decreasing their carbon footprint.	To function, it needs a high degree of sophistication.
2.	It may also assist businesses in lowering the hazards brought by operating an inefficient IT system, such as elevated operational expenses and dangers.	The user should have a solid grasp of the underlying infrastructure and its parts, which calls for a thorough understanding of how the system operates and how the design should be modified to improve energy efficiency.
3.	By dynamically distributing resources depending on their present demands and consumption, DAEM assists companies in achieving better levels of energy efficiency.	Because it necessitates substantial expenditures in hardware and software, dynamic architectural energy management is not always economical

Memory and processors are the power-expandable elements that make up the two DAM strategies.

A. Power-scalable memory: A productive method for managing memory in cloud systems with dynamic power scaling is Memory MISER, created by Tolentino et al. Memory MISER is a triumphant method of ensuring energy efficiency for cloud systems. This system enables on- and off-lining of memory scaling in the system's operating mode by using a patched Linux kernel and a PID controller daemon [17]. Demonstrate Memory MISER to reduce memory energy utilization by 70% and total system energy intake by 30% (with less than 1% execution debilitation) in examinations utilizing both parallel and consecutive programs on a server equipped with 8 processors and 32 GB of Synchronous Dynamic Random Access Memory per CPU [18].

B. Power-scalable processors: The emergence of a fresh, power-capable processor technology for cloud systems has the probable to be highly energy-efficient, as Dynamic Voltage Scaling, Dynamic Frequency Scaling, and Dynamic Voltage and Frequency Scaling can abate the CMOS circuit's dynamic power. Investigations have revealed that running scientific applications on conventional clouds just yields 5-10% of their utmost performance. To amplify the cloud's energy efficiency, Ge et al. [19] presented an offline DVFS scheduling algorithm that utilizes an energy-delay product, allowing the user to assign either performance or energy conservation precedence. This methodology can produce energy savings of up to 30% with no more than a 5% performance degradation on average. However, offline scheduling is advantageous, yet it necessitates applications to be statically scheduled, which might restrict system scalability [19].

Load balancing (LB): To maximize resource efficiency, reduce reaction time, and prevent system overload, LB is a technique used to spread the workload across a computing cloud. LB is a trade-off between the performance of the system and the power supply[20].

IV. Energy-Efficient Computing

With cloud computing becoming more and more popular, it is crucial to use green computing practices to cut down on electricity usage and CO2 emissions. Data centers, which are huge and use a lot of energy, are necessary for cloud computing. 38GW of power, or 63% more than what was utilized in 2011, was used for these data centers, according to information from 2012. In 2013, this amount is anticipated to rise to 43 GW. 5 MW of electricity, enough to power 5,000 homes for a year, is needed to power a single data center that is 50,000 sq. feet in size [21]. Furthermore, these data centers demand 30 billion watts of electricity annually for cooling. This energy can provide 5,000,000 households for 365 days and corresponds to the consequence of nearly 30 nuclear power plants. Better strategies for maximizing the power needed for cloud computing must be developed [22].

Ways to reduce power consumption are as follows:

By using Split plane power: Splitting is the process of dividing something into parts, particularly in the context of a processor. In this context, splitting means dividing the power plane between the processor and the North Bridge, a microchip developed by Intel that bridges communication between the Central Processing Unit and the motherboard. The motherboard is capable of providing split electricity to the processor and North Bridge. Further, the power plane can be split into multiple regions, creating a nested splitting.

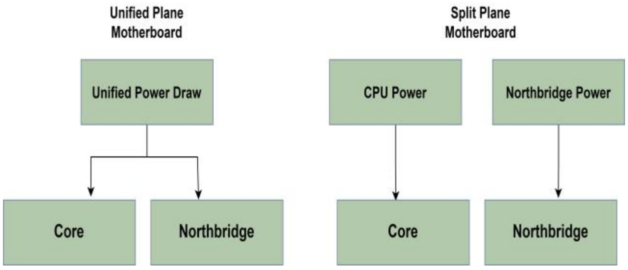

Fig 5. Power in Split Plane [22]

By reducing CPU Power dissipation: The manipulation of electrical energy to run switching devices, cooling transistors, and chips are the responsibility of Processors. Such energy, post-consumption, is discharged into the atmosphere as heat. Products such as mobiles, embedded systems, palmtops, netbooks, notebooks, desktops, and laptops produce heat at a lower level than usual processors. The usage of free cooling helps to reduce the dissipation of energy.

Using advanced Clock gating: A clock gater is a hardware switch that is used to control the clock of a logic block. The switch will activate the clock when the logic block is performing some action and deactivate it when the logic block is idle. This technique is commonly used in synchronous circuits, but can also be used in globally asynchronous, and locally synchronous circuits for reducing power consumption [23].

By using Energy-efficient Processors: The utilization of processors (which is energy-efficient) is done by dynamic voltage and frequency scaling for decreasing the power usage of a CPU. By varying the voltage and clock rate of the processor, the necessity for power can be minimized. This strategy has been utilized for real-time systems. By way of the utilization of these systems, the power utilization of processors can be managed efficiently.

Reducing Cooling Requirements: The utilization of traditional methods of cooling for data centers necessitates the implementation of mechanical refrigeration apparatuses or the application of chilled water, which has been cooled externally, to air handlers. As an alternative system, free cooling seeks to reduce or take away any requirement for mechanical refrigeration. This is accomplished by providing either direct or indirect cooling if the external air temperature is below or is the same as the desired temperature. Although free cooling does not reduce the energy needed for cooling via fans, it does make it possible to forgo any mechanical cooling energy [23].

V. RESEARCH CHALLENGES OF GREEN CLOUD COMPUTING

The burgeoning fame of green cloud computing has caused an augmentation in the number of data centers, which necessitates the requirement for improved solutions that are economical in terms of energy. Organizations should begin building data centers to use renewable sources like sunlight-based and wind energy and decrease the utilization of non-renewable sources. The attainment of energy efficiency is a hazardous undertaking, evoked by the multifarious applications that necessitate being processed, as well as the claim for a high level of performance. Furthermore, companies should take part in e-waste management to protect the environment from the hazardous effects of e-waste. When selecting a location for data centers, convenience is not the only factor to consider. Cooling systems, such as to guarantee effective energy utilization, free cooling, evaporative cooling, liquid cooling, immersion systems, and elevated flooring should be used. Storage can also be optimized by using power saver mode and merging data. Companies should also reduce their use of non-renewable energy sources and participate in e-waste management to protect the environment.

V. CONCLUSION AND FUTURE WORK

There has been a rapid rise in the popularity of green cloud computing, increasing the number of data centers. This necessitates the need for more efficient and cost-effective energy solutions. To reduce energy consumption, a variety of techniques have been implemented, like the virtualization of servers. Numerous research projects are conducting to further ameliorate the ecological effect of data centers by probing into other factors such as networking, storage, and power expenditure.

Reaching energy efficiency is a risky endeavor, caused by the many tasks that need to be done, as well as the requirement for superior performance. To counter this matter, there are some tactics to augment energy efficiency in the clouds. One of these means is to incorporate less power-embedded Central Processing Units with flash storage. Moreover, software and power-scalable subsystems can be utilized to adjust the power consumption of the cloud in an adaptable way. Such systems have exhibited a positive implication for the improvement of energy efficiency, although forming power-aware schedulers is not an uncomplicated task. The power consumption in static and dynamic architecture energy management composes a noteworthy fraction of the absolute power expenditure at middle and high usage rates. Therefore, energy efficiency in cloud computing is a critical issue that needs quick attention.

To diminish the electricity usage of the cloud, a multiplicity of strategies such as virtualization, consolidation, etc. are being utilized, yet further is desired. The article puts forward an assemblage of metrics that can be employed to assess and contrast the power efficiency of distinctive cloud programs. The document also puts forward methods like dynamic power control, distributed computing, and data center power optimization to reduce the power requirement. By employing these techniques, the power performance of cloud applications can be drastically heightened.

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