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Research Article

Optimizing Energy Efficiency in Green Cloud Computing: A Review

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ABSTRACT

The rapid growth of cloud computing has revolutionized how businesses and individuals access and utilize computing resources. However, this growth has also led to significant environmental challenges, primarily due to the substantial energy consumption and carbon emissions associated with cloud data centres. In response, green cloud computing has emerged as a critical field of study aimed at mitigating the environmental impact of cloud technologies through the adoption of sustainable practices and innovative solutions. This review paper provides a comprehensive examination of green cloud computing, exploring key technologies, strategies, and methodologies designed to enhance energy efficiency and reduce carbon footprints in cloud environments. We begin by discussing the fundamental concepts of green computing and its relevance to cloud services. We then review various approaches to improving energy efficiency, including advanced cooling techniques, energy-efficient hardware, and intelligent resource management. The paper also highlights recent advancements in green cloud technologies, such as renewable energy integration, carbon footprint measurement, and green software development. Additionally, we address the challenges and limitations faced by current green cloud practices and propose potential future research directions. By synthesizing the latest developments and identifying critical gaps, this review aims to provide a valuable resource for researchers, practitioners, and policymakers striving to advance sustainable cloud computing solutions.

Keywords: GCC(GreenCloudComputing), EC(EnergyConsumption)

1.INTRODUCTION

The official NIST definition of Cloud computing [1] is as: "Cloud computing is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction." It is also defined as a way of enabling on-demand network access to a shared group of configurable to compute assets like storage, networks, servers, services, applications, etc. that can be swiftly provided and opened with the least amount of administrative effort or provider contact [2].

1.1 Service Models of Cloud Computing

Cloud computing is a model for providing network access to a shared pool of resources that is always available, convenient, and on-demand. With minimal effort, these computing resources may be deployed and released quickly.

Cloud computing is available in three main service models as shown in Fig 1, each of which caters to a particular set of corporate needs. Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS) are the three paradigms (IaaS).

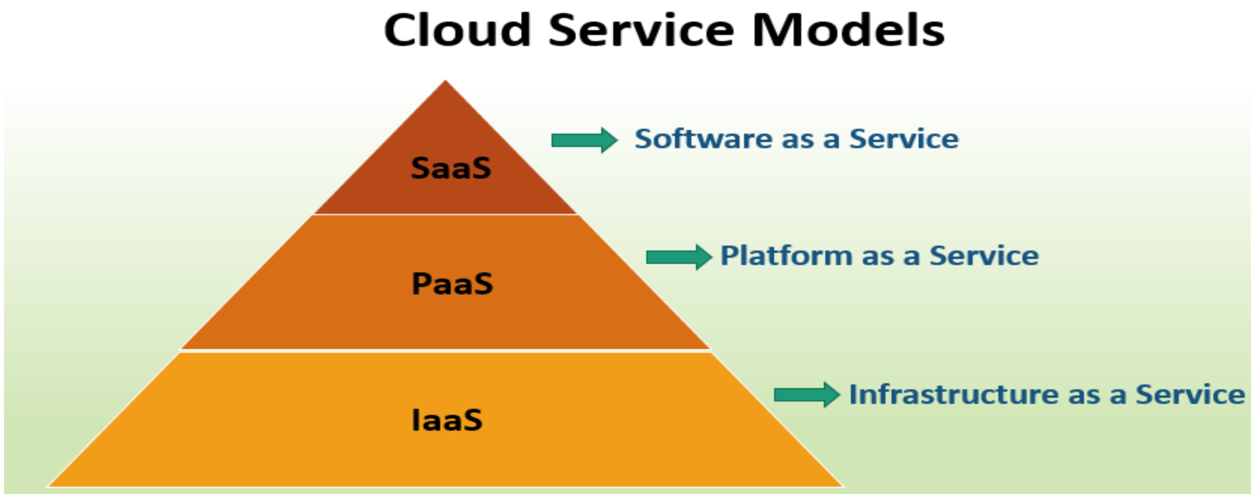

Fig 1: Cloud Computing Service Models

1.2 Deployment Models of Cloud Computing

Cloud computing can be implemented in a variety of ways, depending on the demands, and the following deployment methods have been recognized [3].As shown in Fig 2 each deployment type has its own set of characteristics that cater to the distinct needs of cloud services and clients.

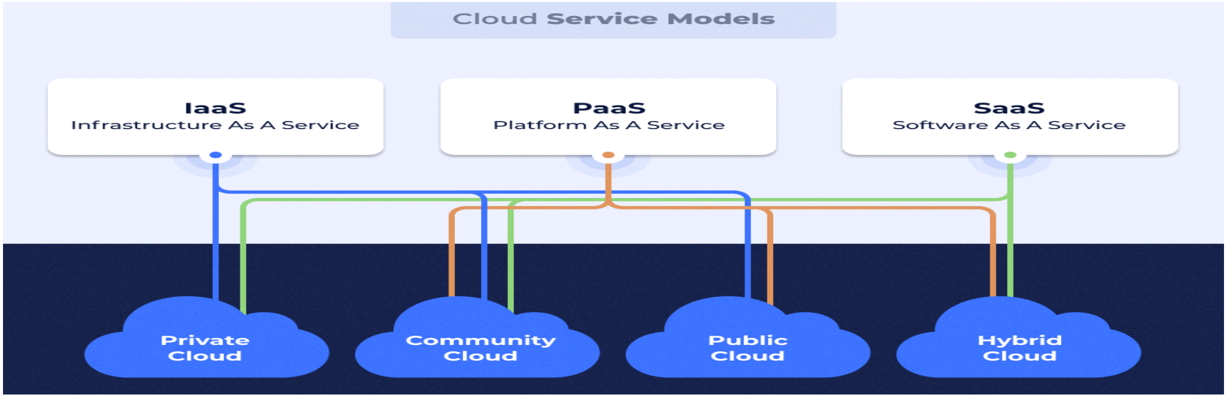

Fig 2: Deployment of Cloud Computing

1.3 Green Cloud Computing

Green cloud computing (GCC) is a vast spectrum and a hot field, as we are well aware. The distinction between "user of" and "producer of" cloud-based energy resources could be crucial in establishing a global GCC ecosystem [4]. With an Internet or wired/wireless network connection, a user just submits a service request to the cloud service provider. The requested service's result is supplied to the user in a timely manner, while the networks smoothly interact with the information storage and processing, interoperating protocols, service composition, communications, and distributed computing. Green cloud computing refers to the delivery of cloud services while taking into account energy usage according to a set of energy consumption standards, and it is known as GCC [5].

1.4 Green Computing Approaches

Green computing is the environmentally responsible and eco-friendly use of computers and their resources [6]. Many IT manufacturers and vendors are continuously investing in designing energy-efficient computing devices, reducing the use of dangerous materials, and encouraging the recyclability of digital devices and paper.

There are various approaches to design and implement green computing [7].

Green use: Minimizing the electricity consumption of computers and their peripheral devices and using them in an eco-friendly manner. This approach is the primary necessity of green computing where energy consumption from various electronics devices is reduced.

Green disposal: Repurposing an existing computer or appropriately disposing of, or recycling, unwanted electronic equipment. This approach focuses on destroying or vanishing not using electronic gadgets or recycling any device or material we can.

Green design: Designing energy-efficient computers, servers, printers, projectors, and other digital devices. It focuses on efficiently using electronic devices through intelligent software algorithms or through hardware changes.

Green manufacturing: Minimizing waste during the manufacturing of computers and other subsystems to reduce the environmental impact of these activities.

1.5 Areas to work on Green Data Center

There are several areas of Green Data Center where various concepts of cloud computing can be implemented and separated. As shown in Fig. 3, for a particular IT building various working areas for implementing green data center can be identified [8].

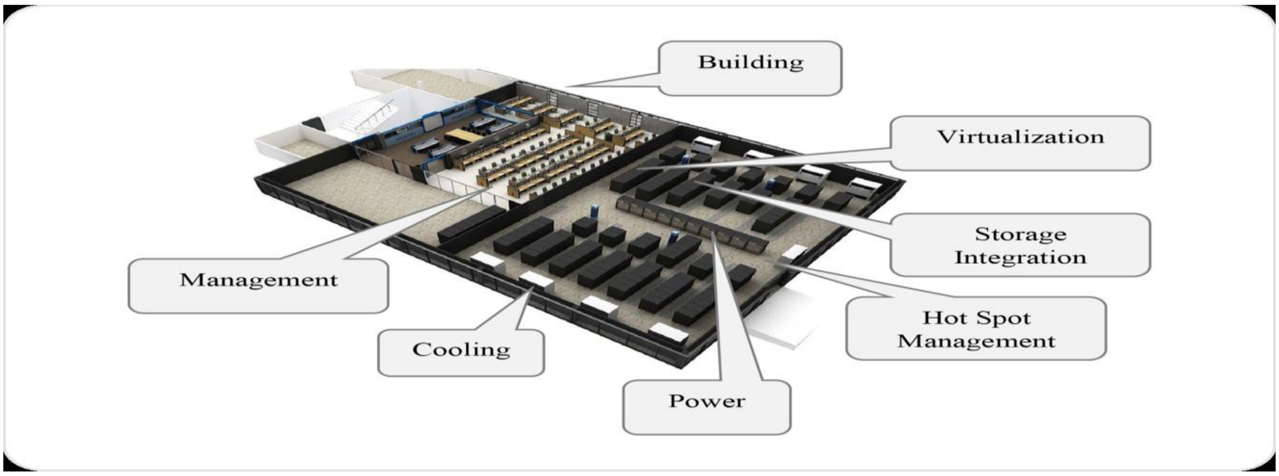

Fig 3 Areas to Work on Green Data Center

The main key areas to work on the green data center are as follows [9]:

Building: Buildings are basically for the avoidance of energy leakage by radiation protection. Also, it should be taken care of no windows in certain areas should be installed.

Virtualization: It is for sharing of physical resources via virtualization and it also downsizes of installation space.

Storage Integration: Integration of storage into a pool via virtualization and improvement of its utilization.

Hot Spot Management: Management of hot spots via analysis of power consumption and usage patterns

Power: It is for diagnosis and estimation of energy, it should use highly efficient UPS, its design must be scalable to UPS load, and it saves space by use of DC.

Cooling: Cooling should be achieved through re-location of equipment by fluid dynamics and inducement of cold air in the winter season.

Management: Managing of individual control of lighting, management of peak power, and real-time PUE management.

2.LITERATURE REVIEW

Cloud computing is best-suited for its potential benefits, and it delivers computer resources such as CPU (Processing Power), memory, storage, networking, and other services as a service [10]. According to the NIST definition, cloud computing is an on-demand and convenient paradigm for computing resources with speedy provisioning and minimal management or service provider involvement. Amazon Web Services (AWS) [11], Google Cloud Platform (GCP) [12], Microsoft Azure [13], IBM Cloud [14], and Alibaba Cloud [15] are among the leading cloud service providers, all of which are doing well and investing extensively to increase their capabilities in many industries. Green

Cloud Computing is a concept that works with cloud resources that can manage energy. It's a key solution for all scalability-sensitive dynamic resource demands.

The growing number of internet users necessitates the establishment of data centers in various zones and geographical regions around the world.According to a report submitted to the US Department of Energy in 2014 [16], data centers in the US consume 1.8 percent of total energy. Data centers emit a large amount of CO_2 [17], which is a major problem for the environment and could result in global warming. Because of this serious problem,

reducing energy use should be a primary goal. The solution to this dilemma will contribute to environmental preservation while also supporting leading firms in reaching significant growth.

Green IT (GIT) is an idea of a green infrastructure program aiming at increasing efficiency and productivity by using and growing resources in companies and society in a sustainable manner. Information Technology (IT) organizations have used GIT to accomplish successful operations with little carbon waste. However, the short lifespan of IT goods, as well as some manufacturing and disposal methods, have sparked widespread concern about negative consequences, such as higher energy use by businesses. Furthermore, the carbon emissions from IT products and systems outnumber those from the aircraft industry. Green computing is a solution to environmental issues [18].

The demand for cloud-based solutions and data centers is growing as global digitization progresses and a large number of mobile and web applications are deployed [19]. An increase in the number of internet users necessitates the construction of more data centers. Increasing data center demand necessitates a massive quantity of energy for data center operation while also emitting a massive amount of CO_2. Researchers have offered a number of methods for reducing energy consumption.

2.1 Literature Overview

In [20], U. Wajid et.al. describes an eco-aware approach that combines innovative application scheduling and runtime adaptation techniques with the definition, monitoring, and utilization of energy and CO_2 metrics to optimize energy consumption and CO_2 footprint of cloud applications as well as the underlying infrastructure. The eco-aware approach entails measuring or quantifying energy consumption and CO_2 emissions at various levels of cloud computing, using that data to develop scheduling and adaptation techniques that help reduce energy consumption and CO_2 emissions and then testing and validating the

developed solutions in a multi-site cloud environment using challenging case study applications. The experimental and validation results suggested that the eco-aware strategy has the potential to drastically reduce CO_2 emissions.

T. Mastelic et.al. in [21], conducted a complete energy efficiency analysis of infrastructure supporting the cloud computing paradigm. First, they established a method for measuring the energy efficiency of the most essential data center domains, such as server and network equipment, as well as cloud management systems and appliances, which are software-based appliances used by end-users. Second, they used this method to examine accessible scientific and industry literature on cutting-edge data center operations and equipment. Finally, they outlined current research difficulties and prospective research directions. As shown in Fig. 4 , the authors have presented energy flow in the system and how energy is entered in the system, energy consumed, energy used, and finally the task is carried out as output.

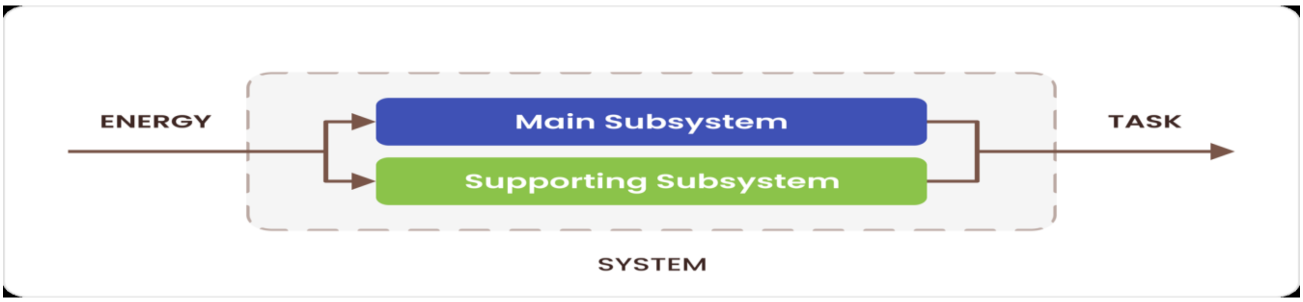

Fig 4: Energy Flow in System

In [22], M. Pantazoglou et.al. described a decentralized method for managing scalable and energy-efficient virtual machine (VM) instances provisioned by big enterprise clouds. The data center's computation resources are successfully grouped into a hypercube structure. As resources are added or deleted in response to changes in the number of provided VM instances, the hypercube scales up and down effortlessly. Each compute node functions independently of any central components and handles its own workload using a set of distributed load balancing rules and algorithms. On the one hand, underutilized nodes

try to offload their workload to their hypercube neighbours by turning it off.

X. Xu et.al. in [23], presented EnReal, an Energy-aware Resource Allocation approach. Essentially, the authors used dynamic virtual machine deployment to execute scientific

workflows. In particular, an energy consumption model for cloud computing applications is provided, and a related energy-aware resource allocation algorithm for virtual machine scheduling to complete scientific workflow executions is used.

In [24], V. Cima et. al. presented variants of live migration as described in Fig. 5. There are three types of live migration. E.g. Pre-copy, Post-copy, and Hybrid live migration.

Fig 5: Pre copy, Post Copy, Hybrid Live Migration

It gives a highlight of how the energy efficiency concept can be added to OpenStack. The main goal is to create OpenStack resource management that is energy efficient. There are two steps to it. In the first step, it is examined how cloud resources are being used in terms of resources and energy. In the second step, there is an approach for static migration based on manual resource consumption monitoring.

N. Akhter et. al. in [25], described different reviews anopen challenges for energy aware resource allocation strategies of cloud data centers. The authors have presented an exhaustive collective summary for energy aware resource allocation methods and virtual machine identification strategies. Fig. 6 represents energy consumption analysis model for the cloud environment.

The data collection engine retrieves users' requests from cloud data centers and sends them to the analysis engine. It also gets cloud resource details and is attached with a policy for the energy consumption model. Simultaneously analysis engine is fed with task description and system configuration details. As an output analysis engine generates analysis results.

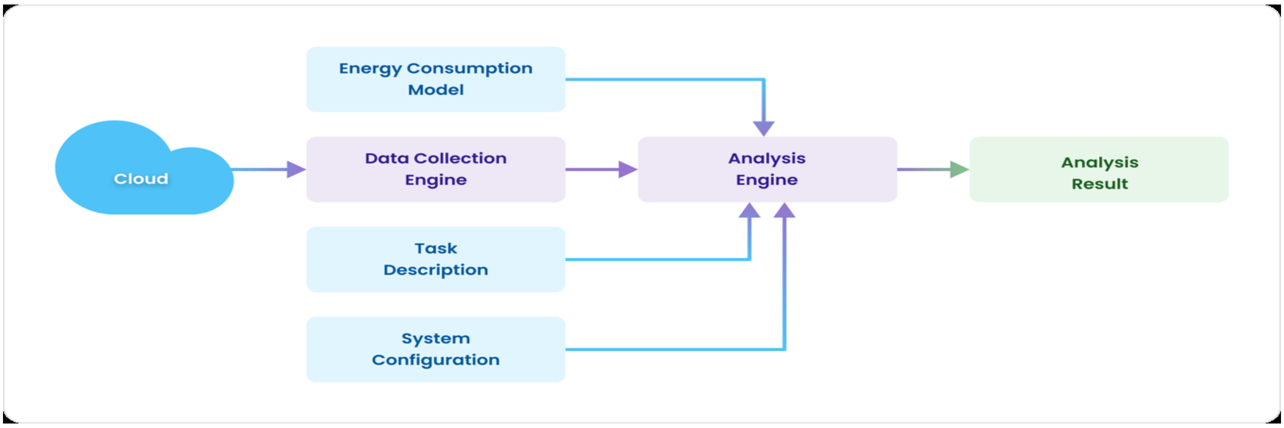

Fig 6: Cloud Consumption Analysis Model

T. Kaur et.al. in [26], presented the importance of energy efficiency by analyzing cloud computing's dual position as a major contributor to increased energy consumption as well as a technique to reduce energy waste. The authors examined existing energy efficiency approaches in cloud computing in-depth and compares them, as well as provided taxonomies for categorizing and evaluating existing research. The paper finishes with a summary that includes helpful recommendations for future improvements.

In [27], Anton Beloglazov et al. have suggested an efficient resource management policy for virtualized cloud data centers. The goal is to continuously condense VMs via live migration and turn off idle nodes to save power while maintaining the appropriate Quality of Service. The authors also offered evaluation results that show that dynamic VM reallocation saves a significant amount of energy, justifying the suggested policy's ongoing development. Due to the trust elements of cloud computing, various areas are explored and proposed to work on energy-efficient methodologies in the cloud environment. The taxonomy of energy efficient architecture of computer systems such as hardware, operating systems, virtualization, and data centers have been proposed in this paper.

David Aikema et al. [28] proposed a VM migration strategy with two approaches: in the first, authors calculated migration time and associated energy consumption, whereas in the second, they directly migrated all workload to accessible other VMs based on threshold values. The authors established a correlation with many scenarios, concluding that determining migration time and needed energy utilization computation is really beneficial.

The authors presented the findings of an experimental investigation of the power and energy consumption of various workloads throughout the migration process. The authors concluded about the sorts of workloads that are suitable for migration and how each can be converted successfully.

Minu Bala and Devanand in [29] focused on CO_2 emissions and VM migration based on CPU utilization parameters in one of the strategies for VM migration. They modified the upper and lower thresholds of the CPU limit, based on which VMs are migrated to different data centers on different hosts. In order to reduce power consumption, various green computing solutions have been investigated, both at the hardware and software levels. The experimental study shows a simulation environment that captures the energy consumption of computing and communicating devices in the cloud. It also demonstrates how a variety of green computing solutions outperform standard computing approaches based on various data center designs.

In a cloud computing context, K. Zhang et al. [30] considered virtual machine (VM) energy saving solutions on an overloaded host. They researched the energy affecting factors and developed energy efficient VM selection strategies based on greedy algorithms and the dynamic programming process during a VM migration. A range of green computing solutions have been researched at both the hardware and software levels in order to reduce power usage. The lab experiment exhibits a simulated environment that depicts the energy usage of cloud computing and connectivity devices. It also shows how a variety of green computing solutions outperform standard computing approaches based on various data center layouts.

Junaid Shuja et al. [31] conducted research on green computing techniques in the context of current IT tools in our community. This article discusses practical green computing solutions as well as the trade-off between green and high-performance projects. They also looked at the challenges that increasing IT technologies face in terms of green operational efficiency. In the midst of the rising IT technologies that are obvious in contemporary society, this article provides a review of green computing strategies. Green computing best practices and the trade-off between green and high-performance rules are discussed. The upcoming problems that emerging IT technologies will face in terms of running efficiently green operations are also gone through.

Ali Hammadi et al. [32] divided existing Data Center Network (DCN) architectures into switch-centered and server-centered topologies, as well as various energy-saving strategies. To optimize energy consumption for OpenNebula-based Cloud.

Yacine Kessaci et al. [33] suggested an EMLS-ONC method. The authors created the EMLS-ONC (Energy-aware Multi-start Local Search algorithm for an OpenNebula-based Cloud), which minimizes the energy consumption of a geographically scattered OpenNebula-managed cloud computing infrastructure. Our EMLS-ONC scheduler's output is compared to OpenNebula's default scheduler's output. The two approaches were tested using a variety of (VM) arrival scenarios and hardware architectures. The results show that EMLS-ONC significantly beats the previous OpenNebula scheduler in terms of energy consumption. EMLS-ONC has also been shown to help schedule more applications. A User-Priority Guided Min-Min Scheduling algorithm has been developed by Huankai Chen et al. [34]. Two distinct strategies have been offered by the writers. Priority Aware Load Balance Improved Min-Min (LBIMM) and Load Balance Improved Min-Min (LBIMM) (PA-LBIMM). When compared to the Min-Min algorithm, the results of LBIMM and PA-LBIMM are far superior in terms of job completion time, resource load balancing, and overall system performance. This new method improves system performance by more than 20% in terms of resource consumption and user services.

In cloud computing, Veerawali Behal et al. [35] suggested a Load Balancing method for Heterogeneous Environments. The authors present a throttled strategy for dealing with optimal reaction time. Using broker policy, this strategy improves performance in a distributed cloud system.

Yunliang Chen et al. [36] suggested a two-tier VM placement architecture based on a feasibility-driven stochastic VM placement (FDSP) method to reduce VM placement energy usage. When compared to conventional algorithms, the suggested algorithm consumes 15.3 percent less energy and costs 15.7 percent less than other VM placement rules. To determine the best cost for VM placement in cloud-based data centers.

Sourav Kanti ,Addya and Anurag Satpathy [37] suggested a Game theoretic technique. To get the precise value for capital expenditure, the authors analyzed n-users in a cooperative gaming context. Integer linear programming is offered as an energy-efficient placement policy, with Microsoft Azure and Amazon EC2 as cloud service providers. Finally, the authors' proposed game theme method is more effective than first fit decreasing (FFD) and improved first fit decreasing (EFFD) in terms of utilizing less energy (EFFD).

C. Yang et.al. in [38], proposed a green power management scheme based on the virtual machine cluster's gross occupied resource weight ratio, estimate how many physical machines should be run or shut off. The ratio of the total of virtual machine resource weights to the sum of available resource weights of all running physical machines is known as the gross occupied resource weight ratio. When the gross occupied resource weight ratio exceeds the maximum tolerated occupied resource weight ratio, a standby physical machine in the non-running physical machines is picked and woken up to join as one of the operating physical machines to assure the quality of service. When the gross occupied resource weight ratio falls below the minimum critical occupied resource weight ratio, which is used to trigger energy-saving algorithms, one of the running physical machines is designated as a migration physical machine, and the virtual machines on it are removed after live migration.

Khosravi A., et.al. in [39], proposed a unique VM placement method that takes into account remote data centers with varying carbon footprint rates and PUEs to improve environmental sustainability. In comparison to existing competitive algorithms, simulation results show that the suggested algorithm reduces CO2 emissions and power usage while maintaining the same level of service quality.

Kansal, A., Zhao, F., et.al. in [40], proposed a metering feature for VM power capping, an approach for lowering data center power provisioning costs. Experiments are run on server traces from tens of thousands of production servers that host real-world Microsoft programs like Windows Live Messenger. The findings reveal that not only does VM power metering allow virtualized data centers to save the same amount of money that non-virtualized data centers did with physical server power capping, but it also allows virtualization to save even more money on provisioning expenses.

Aryania, A. et.al. in [41], solved the problem of virtual machine consolidation tries to reduce the energy consumption of cloud data centers using Ant Colony Optimization. ACO significantly reduces the number of migrations and active physical machines, lowering total data center energy consumption. ACO outperforms the state-of-the-art VM Consolidation algorithm in terms of migrations, sleeping PMs, SLA violations, and energy usage in a small number of cases.

In [42] [43], authors have proposed Particle Swarm Optimization (PSO) based technique used to resolve the workflow system task scheduling optimization problem in cloud computing. The scheduling scheme's execution cost and time are higher than other techniques, and the convergence accuracy is enhanced. It can keep you from falling into the local optimality too soon.

V. Cima, B. Grazioli et.al. in [24], presented how energy efficiency aspects can be added to Openstack. They begin by analyzing resource and energy use on cloud resources in order to create an energy efficient resource manager for Openstack. They discovered that server utilization patterns had a significant fixed cost and that turning down servers is required to save energy. Authors devised an energy efficient resource manager for OpenStack by analyzing resource and energy utilization on cloud resources and static migration approach based on the manual monitoring of resource utilization. Authors also categorized variants of live migration as pre-copy, post-copy, and hybrid live migration.

Chen, Feifei et.al. in [44], designed an energy consumption model for cloud computing systems. Authors conducted comprehensive tests to profile the energy consumption in cloud computing systems based on three categories of workloads: computation-intensive, data intensive, and communication-intensive tasks, in order to operationalize this model. With a variety of system configurations and workloads, authors gathered fine-grained energy usage and performance data. The correlation coefficients of energy consumption, system configuration, and workload, as well as system performance in cloud systems, are shown in experiments. These findings can be utilized to create energy consumption monitors as well as static and dynamic system-level energy consumption optimization algorithms for green cloud computing systems. The energy consumption model is described as follow:

• Fixed Energy Consumption (ECFix): Energy consumption during idle time and energy consumption of the cooling system.

• Dynamic Energy Consumption (ECVar): Energy consumption by running tasks in the cloud system.

$$ECTotal = ECFix + ECVar \quad (1)$$

3. COMPARITIVE REVIEW

In following Table 1, various existing research papers are compared on the basis of used parameters and their advantages for various cloud data center solutions.

Sr No	Title Of Paper	Parameter Used	Advantages
1	On Achieving Energy Efficiency and Reducing CO2 Footprint in Cloud Computing [20]	CPU Storage CO2 measurement	Calculate power usage after shutting off idle hosts.
2	Cloud Computing: Survey on Energy Efficiency [21]	Network Server CMS Appliance	By considering various domain studies like Network, Server, CMS, and Appliance, easy to identify energy consumption for each. Detect energy consumption and energy loss for each domain
3	Decentralized and Energy Efficient Workload	CPU Network	Based on current power consumption, there are five VM states. E.g. Switched off,

	Management in Enterprise Clouds [22]		Idle, Underutilized, Ok, Overutilized, which makes power utilization regularized. Algorithms for workload management. 1. Initial VM Placement 2. Partial VM Migration 3. Full VM Migration
4	EnReal: An Energy-Aware Resource Allocation Method for Scientific Workflow Executions in Cloud Environment [23]	CPU Memory Storage	Calculate energy consumption based on • application executions • dynamic operations Allocation of resources to run a present application, Dynamic operations planning, With proper resource allocation, power consumption can be reduced
5	Energy Efficiency Techniques in Cloud Computing: A Survey and Taxonomy [26]	ICT Hardware CPU Distributed / parallel execution parameters	Energy consumption by various industries Power aware technique using Virtualization approach QoS and SLA benefits Migration approach
6	Joint Resource Provisioning for Internet Data centers with Diverse and Dynamic Traffic [45]	Queue based scheme	Queue based scheme used to provide the best QoS and less rejection rate Power consumption and Cost model implemented Cost Op
7	Experimental Analysis of Task- based Energy Consumption in Cloud Computing Systems [44]	CPU	Create VM CPU footprint for workload and resource allocation Calculate Energy consumption for predefined tasks Calculate Energy consumption for dynamically running tasks
8	Energy aware resource allocation of cloud data center: review and open issues [25]	CPU Memory Network	Calculate VM and Physical Host Energy Consumption A log of VM and Physical Host energy consumption was established, and resource allocation was controlled based on it.
9	Energy Efficient Allocation of Virtual Machines in Cloud Data Centers [27]	CPU Memory Storage	VMs that use live migration and turn down inactive nodes to save power while maintaining the requisite Quality of Service
10	Green Cloud VM Migration: Power Use	CPU Storage	The many types of workloads that can be transferred and

	Analysis [28]	Network	how they can be migrated most efficiently
11	Performance evaluation of cloud data centers using various green computing tactics [29]	ICT Hardware/ Software, Network	The effectiveness of various green computing strategies in comparison to traditional computing approaches employing various data center layouts.
12	Virtual Machine Migration in an Over-Committed Cloud [30]	ICT Hardware/ Software Network	Placement and migration of virtual machines, with host use balanced across all time epochs
13	Greening Emerging IT Technologies: Techniques and Practices [31]	CPU Network	Review of green computing techniques in the context of current society's rising IT technologies
14	An Energy-aware Multi-start Local Search Heuristic for Scheduling VMs on the OpenNebula Cloud Distribution [33]	ICT Software CPU	In terms of energy usage, EMLS-ONC outperforms the old OpenNebula scheduler by a large margin.
15	User-Priority Guided Min-Min Scheduling Algorithm For Load Balancing in Cloud Computing [34]	ICT Software CPU	PA-LBIMM was created so that users' demands may be met on a need-to-know basis

Table 1: Comparative Analysis

CONCLUSION

In this paper, the literature has been reviewed and concluded that various previously proposed methods have their own advantages and disadvantages. There is a lot of scope for proposing energy efficient solutions for cloud data centers. There are lots of parameters and situations which may affect the energy efficient solutions for the cloud.

This summary provides an overview of the main topics and themes that are likely covered in a review paper on optimizing energy efficiency in green cloud computing. The paper would aim to provide a comprehensive understanding of the current state of energy efficiency in cloud computing and offer insights into how it can be improved.

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