Energy-Efficient Cloud Data Management: Innovations in Sustainability

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Abstract

The rapid expansion of cloud computing has led to a significant increase in energy consumption and CO2 emissions from data centers, necessitating urgent strategies for energy efficiency. This research synthesizes various approaches to enhance energy-saving systems within cloud environments, focusing on four key areas: the design of energy-efficient hardware, the development of optimized software solutions, user education, and the establishment of uniform regulations. Advancements in artificial intelligence and resource management, as demonstrated by Alibaba's data center in Hangzhou, illustrate the potential for achieving a Power Usage Effectiveness (PUE) of 1.30, marking a significant improvement over traditional data centers. This paper provides a comprehensive overview of green computing initiatives, emphasizing the importance of cloud technology in minimizing environmental impact while meeting the growing demand for computing services. By addressing the challenges of energy consumption in cloud data centers, this study contributes to the ongoing discourse on sustainable computing practices and offers actionable insights for future research and implementation.

Keywords: - Cloud Computing, Energy Efficiency, Data Centers, CO2 Emissions, Green Computing, Sustainable Practices.

I. Introduction

Cloud computing is one of the main growth areas in technology and communications. Better internet access and new wireless technology let devices stay connected all the time, which makes new types of services possible. More and more people use computers, especially mobile ones, and social networks are becoming popular (McDonald, 2010). Because of this, cloud services are becoming more important as they are more flexible than traditional programs that only work on one computer. This new way of handling information creates big energy use problems for both system parts (Priya et al., 2012). Large data centers use a lot of energy, which leads to a strong need to find ways to save energy for economic and environmental reasons. At the same time, mobile devices need to manage their energy well to make their batteries last longer (Liang et al., 2012).

This benefit has caused an uncontrolled increase in big data centers worldwide, leading to high energy use, more operating costs, and increased CO2 emissions (Pallis, 2010). So, managing power has become a major issue in big cloud computing systems (Zhang & Fu, 2011). A report by Koomey (2011) found that energy use in data centers globally increased by 56% from 2005 to 2010, about 1.1% each year. Venkatraman (2012) has said that a worldwide survey of data centers found that the total energy needed increased by 63% (38GW) from 2011 to 2012. Also, the amount of power used by data centers grew from 12 GW in 2007 to 24 GW in 2011, reaching about 43 GW in 2013. The amount spent on data centers increased by 22% in 2012, from $86 billion in 2011 to $105 billion in 2012. The total energy used by the data center is shown in Figure 1 (Dewitt, 2012).

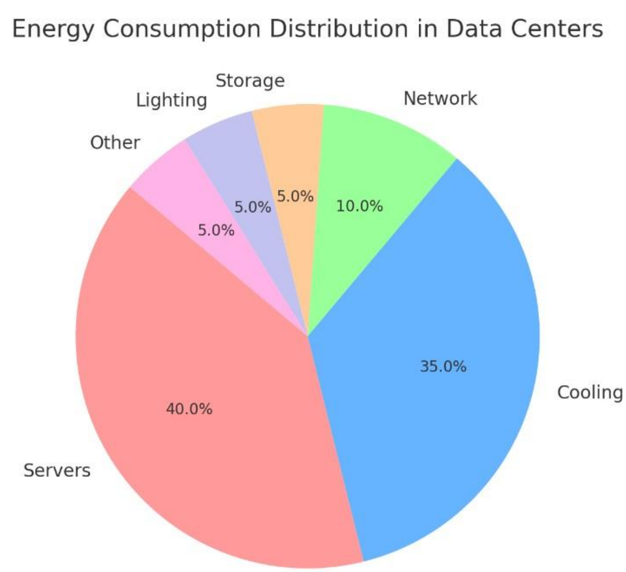

Figure 1: Energy Consumption Distribution in Data Centers

Creating data centers that use less energy and reduce harmful gas emissions is very important in information and communication technology (Uddin & Rahman, 2012). Sustainability has become more important to software and hardware developers and users in the last twenty years because energy use has risen quickly. Koomey (2011) says the effects of cloud computing on the environment have been looked at to support eco-friendly and sustainable growth. These can greatly help the environment by reducing the harmful effects that have worsened over the past few decades. Producers feel a lot of pressure to follow environmental rules and to create products and services that harm the environment less (Masanet et al., 2013). When we talk about technology and computers, the eco-friendly features of products and services are connected to ideas like green technology, ecological informatics, environmental informatics, sustainable computing, and green computing. According to Hilty et al. (2006), when making choices about the sustainable development of cloud computing, it is important to consider how cloud computing affects the environment, both in good and bad ways, now and in the future. The appeal of technology has often caused both makers and users to overlook environmental problems. Their level of maturity, along with pressure from global environmental groups, has led to a change in using technology to follow environmental rules. It is also clear that people want to keep an eye on and take care of the environment. However, there are some challenges to creating and using sustainable strategies in cloud computing. These challenges include high costs, insufficient time or interest to handle the problems that come with these strategies, a lack of concern for environmental effects, and poor teamwork between different company departments.

1.1 The Problem

The EPA says that in the last five years, a lot of energy has been wasted because more people are using computers. The energy used by servers and cooling systems has also doubled (EPA, 2007). When data centers get bigger, or new ones are built, it leads to more carbon dioxide emissions, higher electricity use, and increased energy costs. Between 2005 and 2010, the amount of electricity used by data centers worldwide increased by about 56%. In 2010, the United States used about 2% of all the electricity in the world. Out of that, data centers used 1.3% of the total electricity (Koomey, 2011).

Companies spend millions of dollars on cloud services. Running more physical machines uses more energy. We can control resources like CPU and RAM using smart energy-saving methods to reduce power use in cloud data centers. This helps us lower energy consumption while still getting the job done. Unlike traditional computing, which aims for the highest performance, energy-efficient systems focus on using less power while improving performance. Table 1 shows how much each part of the cloud and its smaller parts costs (Greenberg et al., 2010).

Table 1 shows that CPU, Memory, and Storage make up 45% of the expenses. So, finding the best algorithm that uses less energy and costs less would help lower the energy used by these three parts, which would reduce CO_2 emissions indirectly (Yamini, 2012). More people are using cloud computing, leading to higher energy use, costs, and a greater need to reduce CO_2 emissions. This has led to suggesting methods and algorithms that save energy to make data centers more sustainable.

Table 1: Data Centers, Costs, Component and Sub-Components

Cost	**Component**	**Sub-Components**
45%	Servers	CPU, memory, storage system
25%	Infrastructure	Power distribution and cooling
15%	Power draw	Electrical unit costs
15%	Network	Links, transit, equipment

This research aims to find the best algorithms that use energy wisely while meeting other important needs like using resources well, saving energy, being affordable, and reducing CO_2 emissions. Turning off parts of systems when they are not being used is an important part of Energy Aware Computing. In other words, using virtual machines (VM) to reduce the number of physical machines (PM) is the main idea behind the chosen methods.

Ii. Background And Related Work

2.1 Overview of Cloud Computing

Cloud computing is important because it provides flexible and powerful computer services. It allows users to access complex programs and store data without extra computer resources. It uses cloud data centers with virtualization technologies to provide a strong and flexible computing setup. Many organizations are interested in this idea because it can help save money by spending less on hardware and software (Armbrust et al., 2009). *Cloud computing* is an old idea that is finally becoming popular now. Service-Oriented Architecture (SOA), Microservice Architecture, parallel computing, distributed computing, grid computing, virtualization, and containerization are the main ideas behind cloud computing (Youseff et al., 2008). Some of these concepts are older, like parallel computing, distributed computing, and virtualization. Others are newer, like SOA, Microservice Architecture, grid computing, and containerization. Cloud computing solutions are very flexible. They are constantly getting better in both the hardware and software parts.

Heininger (2012) says that the new way of using technology in cloud computing has some key features: it is everywhere, focused on services, can grow as needed, costs depend on use, and allows users to handle things independently. The idea is mostly explained by its features. The National Institute of Standards and Technology (NIST) describes cloud computing as a way to easily access shared computer resources, like networks, servers, storage, applications, and services, whenever needed. These resources can be quickly set up or removed with little management or help from service providers (Mell & Grance, 2009). As Buyya et al. (2009) stated, a cloud is a system comprising many connected computers that work together. These computers are set up to provide services as a single resource based on agreements between providers and users. Cloud computing combines different technologies and ideas to use physical and digital resources best. The resources are used as services and can be accessed by users based on their needs. There are three main types: IaaS (Infrastructure as a Service), PaaS (Platform as a Service), and SaaS (Software as a Service). IaaS and PaaS offer services to software companies and developers, while SaaS offers services to final users.

A system for classifying cloud computing should look at how easy it is to access. This will help categorize it as private, public, hybrid, or community (Figure 2).

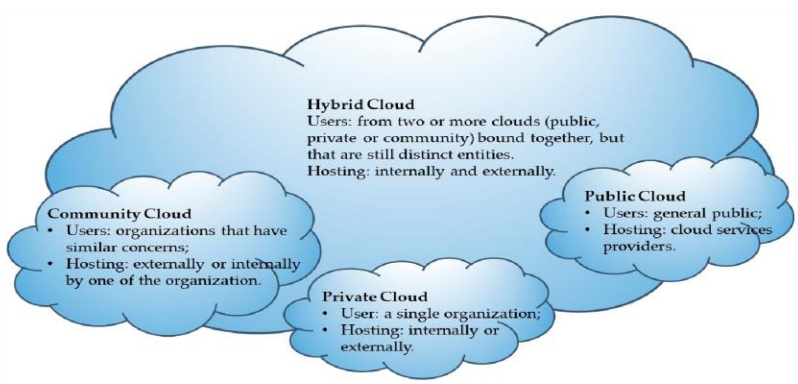

Figure 2: Types of cloud computing

Kliazovich et al. (2012), this paper explains that a cloud computing data center is a group of computer and communication resources designed to change electricity into computing tasks or data transfer. This helps meet the needs of users. This definition talks about how energy-efficient the IaaS model is. SaaS helps the environment by reducing the need for a lot of equipment. It does this by centralizing processing and sharing services, which means fewer data centers are needed. SaaS companies can provide eco-friendly software services that use green data centers with fewer copies or methods that make software use less energy without breaking any service agreements. Cloud providers have more money and a bigger reason to focus on saving the environment than individual users do. For PaaS, providers could give tools like eco-friendly scheduling and green compilers. To support the environment with green cloud computing, SaaS and PaaS providers have ways and tools to make software use less energy.

More people and businesses have started liking cloud technology because it provides many advantages. These benefits include adapting easily, recovering quickly from problems, spending less on technology, improving teamwork among organization members, and automatically getting software updates. Cloud computing appeals to business owners because it allows them to get more resources when their company grows easily. Cloud computing helps the environment in a few ways: it uses energy better, needs less equipment, and produces lower carbon dioxide emissions. This also means less electronic waste (Masanet et al., 2013; Kilazovich et al., 2012; Liu et al., 2009).

To move to cloud computing, businesses may have to change their software and hardware, have problems transferring data, and worry about how well different systems work together (Gai & Li, 2012). These technologies have some risks, especially when it comes to safety. Even with this, cloud computing is still becoming more popular because it gives companies significant advantages, like access to powerful computing resources and large storage, all at lower prices. The sections below explain the main environmental issues found in research and general studies.

2.2 Need for Energy-Efficient Techniques

Data centers use about 1.4% of the total energy consumed, and this amount is growing by 12% each year (Kitchenham et al., 2009; Kitchenham, 2004; Kitchenham, 2004; Barroso et al., 2013). Green cloud computing is a new field that is gaining interest from researchers around the world (Bawdy, 2016). Today, we need this type of technology to balance energy use and performance. One of the main goals of the cloud is to share work evenly and ensure that users can access services from anywhere at any time. Using less energy might lead to breaking the rules set in a Service Level Agreement (SLA). If cloud service providers break these rules, they could face penalties. Therefore, we should try to avoid breaking the SLA while looking for ways to save energy (Kitchenham et al., 2009)

A new report from Accenture says that small and medium-sized companies can cut their carbon dioxide (CO2) emissions by up to 90% if they move to cloud services. Even big companies can lower their emissions by at least 40-60% if they set up all their systems in the cloud. Most data centers mainly focus on cutting down electricity costs and do not pay much attention to carbon emissions. So, the goal is to get rid of the source of CO2, too (Kitchenham, 2004).

If data centers are built using eco-friendly methods, the advantages of cloud computing for the environment become even clearer. Big data centers are usually made for cloud computing. They are linked to many fast networks and virtual servers (Kitchenham et al., 2009; Kitchenham, 2004; Barroso et al., 2013; Bawdy, 2016). They also have things like temperature control and power systems to keep everything running smoothly (Kitchenham, 2004).

An energy drop happens when energy is sent to a process but is not used by any part of it (like D1). For example, electricity can be wasted during transfer or change. Another reason for the decline is the extra costs of running the support system, like cooling and lighting in data centers that are mainly provided by cloud service companies. Power loss happens when energy is used but wasted because the system is not being used properly. For example, this can occur when a system is running but not doing any work (Belkhir & Elmeligi, 2018; Beloglazov et al., 2010; Beloglazov & Buyya, 2010; Beloglazov et al., 2012; Bharany et al., 2018). Another reason for wasting resources is using more than needed or using things unnecessarily, like trying to cool the system to the highest level at night when it is already cool outside.

Cutting down energy use in cloud data centers and cloud computing is a tough problem that has interested many researchers. It has become a popular area of study today.

2.3 The Importance of Saving Energy in Cloud Data Centers

Cloud computing has become an important new way of using technology. It offers a strong and flexible way to use a computer for all IT needs, like storing files and using software. A cloud data center can provide strong and efficient computing power by using virtualization. This idea has spread a lot, and many organizations are interested in cutting down on their spending on hardware and software (Bawdy, 2016). It saves money when many users share the same resources and pay only for what they use without needing to invest money upfront. This allows for easy growth and adjustment as needed.

The main ideas in cloud computing include grid computing, parallel computing, virtualization, containerization, and distributed computing. Right now, popular topics are microservice architecture and service-oriented architecture (SOA). Cloud technology has recently come up to help users who need a lot of computing power by using virtual resources. The cloud can be found and used all over the world through the internet (Bharany et al., 2018; Big Power, 2013). Many cloud data centers have been created, providing a lot of computing power.

These data centers contain large servers that need extra equipment, like storage space, cooling machines, and backup systems (Rajkumar & Sukhpal, 2018; Cisco Global Index, 2018; Damien et al., 2012; Das et al., 2018; Cavdar & Alagoz, 2012; Dybå et al., 2007; Bohra & Chaudhary, 2010; Easterbrook et al., 2008) Also, the many servers in the data center use a lot of space and use a lot of electricity. These servers get hot and need to be kept in a fully air-conditioned space made just for data centers. Data centers are likely to use a lot more energy very soon (Kupiainen et al., 2015).

An estimate predicts that the amount of electricity used by data centers around the world will grow by 1.3% to 8% from 2010 to 2018 (Beloglazov et al., 2010). The big rise in energy use by data centers shows that many data centers and servers are reacting to the increasing need for cloud services (Liu et al., 2018; Chen et al., 2012). This usually means that energy is wasted because not all the power given to a data center is used for cloud storage tasks.

The cooling system uses a lot of energy all the time. In old data centers, about 50% of the capacity is taken up by machines that are not servers (Barroso et al., 2013). These data centers are not using the most efficient ways to manage energy in their design and operation yet. The industry has made a lot of progress in this area. So, ways to make data centers use less energy now depend a lot on figuring out how to make the servers in them more energy-efficient (Kupiainen et al., 2015; Liu et al., 2018; Chen et al., 2012; Farahnakian et al., 2015).

2.4 The Current Status of Cloud Energy Efficiency

As technology in the cloud improves and more people work together online, connecting from different places has become possible (Meisel et al., 2018; Murtazaey et al., 2011). Most cloud companies, like Amazon, Google, Microsoft, Sun, and IBM, are working on making better data centers. This helps them build stronger systems for global data centers (Naseer Qureshi et al., 2018).

These data centers need a lot of power to run things like network equipment, monitors, cooling fans, machines, and air conditioners. The energy used by data centers around the world is 65% more than last year. Both problems are caused by using a lot of energy and producing greenhouse gases (Cameron, 2013; Kamiya, 2018). We can think that cloud-based systems might contribute to global warming because the gases produced by cloud storage, like carbon dioxide and carbon monoxide, have caused serious issues for our environment (Markandey et al., 2018)

If data centers do not reduce their electricity and power use, it will worsen global warming and help a smart economy, which is important for protecting the environment. According to the forecasts, the expected cost of cloud services for the Amazon website and running its data centers is about 53 percent of the total budget. Energy costs make up 42 percent of the total expenses. This includes the power needed to run the system and keep things cool (Hamilton, 2009).

Data centers currently use about 2% of the world's energy, but it is expected to increase to 8% by 2030. Research from Hewlett Packard Enterprise shows that only around 6% of all the data we create is actually being used. This means that 94% is likely stored in a big online account that would create a lot of carbon emissions if it keeps running in circles (Mishra et al., 2018). In 2018, there were 33 zettabytes of data in the world. However, according to a prediction by the International Data Corporation, this amount will grow to 175 zettabytes by the end of 2030. Today, our community creates around 2.5 quintillion bytes of data every day. This data gets stored and managed in data centers, which causes an increase in the energy used by these cloud data centers over time.

Problems with using energy efficiently have grown over time due to new developments in the computer industry that require a lot of energy (Lombardi & di Petro, 2018). This part is about making data centers use energy more efficiently. We need to look into how more energy use in data centers affects the environment. This article examines different ways to save energy that is being used in cloud data centers. To lower the energy use of data centers, we also need to invest in renewable energy sources (Masanet et al., 2018).

2.5 Techniques Used for Energy Efficiency

There are several ways to use energy better and make resources more dependable. There is room to make energy-saving methods better, along with smart ways to share resources. This includes using eco-friendly control methods, managing resources efficiently to save heat, organizing virtual machines, and adjusting resource allocation based on how much is being used now.

Different countries are now charging taxes on greenhouse gases, like CO2 released by IT companies. The total cost of cloud services goes up because of wasting energy, which is important to understand different methods. We split these methods into seven groups, as shown in figure 3. Management at the hardware level, software level (like virtualization and combining resources), and being mindful of power use. This includes methods based on temperature, nature-inspired ideas, and other different approaches, including non-technical ones. These are the basic methods to lower energy use and connect them together. The newest hardware, like the latest processors, uses less energy than the older ones.

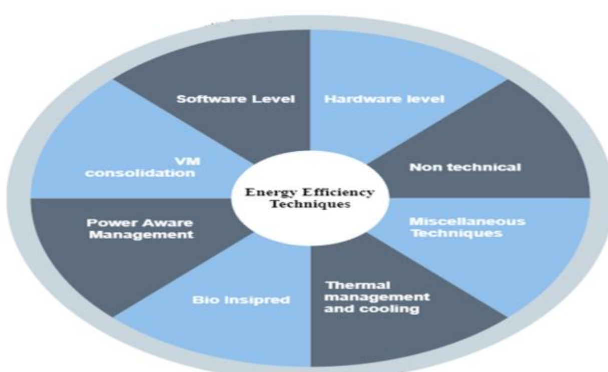

Figure 3: Types of techniques for energy efficiency

Also, we can make the server work better by adjusting its frequencies and voltages. The software program affects energy use a lot more (Cameron, 2013). It mainly focuses on saving energy for servers by using fewer servers and reducing the number of memory nodes that are running. Methods that lower the amount of data moving between servers use less energy when working (Yapicioglu & Oktug, 2013). Power management is about how we use resources and change methods to use energy more efficiently. In the end, non-technical work involves creating plans for organizations and data centers (Kurp, 2008). This also helps save energy. Weather and local renewable energy sources are important for saving energy.

2.6 Assessing the Environmental Impact of Traditional Cloud Computing

The growth of traditional cloud computing has helped improve technology and access to information, but it has also raised big worries about its effects on the environment. This section looks closely at how traditional cloud computing affects the environment, highlighting the main reasons for its negative impact.

Energy Use Patterns: Regular cloud data centers, with their large groups of servers and high energy use, show significant patterns of energy consumption. The constant need for computer power, storage, and data transfer takes a lot of electricity, which usually comes from large sources that cannot be replaced and harm the environment. Knowing how people use cloud services is important for understanding their total effect on the environment.

Carbon Emissions and Climate Effects: The carbon emissions from regular cloud data centers are a big part of their impact on the environment. Relying on fossil fuels to generate electricity for these data centers increases greenhouse gas emissions, which makes climate change worse. Measuring and studying these emissions are important steps to understand how cloud computing affects the environment.

Using cloud computing not only raises energy issues but also leads to using up natural resources: This happens because making hardware parts requires a lot of materials. The ongoing process of replacing old computers and equipment creates a lot of electronic trash, which puts more pressure on our environment. This chapter looks at the different stages of cloud computing infrastructure and focuses on the environmental impact at each stage.

Water Use and Environmental Impact: Water is very important for keeping data centers cool, but the large amount of water used by traditional cloud systems puts a strain on the environment. Using and taking water from nature can affect local plants and animals, making it hard to manage water in a way that lasts. Looking at water use is important to fully understand the environmental effects of cloud computing.

One problem with measuring the impact on the environment is that there aren't common ways or systems to report and evaluate it: The lack of clear and agreed-upon ways to measure and report the environmental impact of cloud services makes it hard to compare them and understand their effects. This chapter talks about the importance of having common measurements to help make clear and fair assessments.

2.7 Related Work

This section talks about the current research done on Cloud computing. It shows how this work is alike and different from other works. And talks about the problems that still need more study.

Madni et al. (2016) looked at different methods for allocating resources. Madni et al. (2016) discussed problems with managing resources in IaaS Cloud computing. It looked at plans and rules for organizing resources that other studies have used. It explained these plans by showing the problems they addressed, the methods they used, and how they measured their results. The paper looked at different plans and compared the details used, highlighting their benefits and drawbacks. In the end, the authors noticed that many current methods did not include important factors like workload, average resource use, and flow time. They called for better versions of these methods. However, their review did not focus on energy-saving Nature-Inspired optimization methods.

Kalra and Singh (2015) looked at five problem-solving methods: Ant Colony Optimization (ACO), Genetic Algorithm (GA), Particle Swarm Optimization (PSO), League Championship Algorithm (LCA), and BAT algorithm, all related to scheduling tasks. The authors looked at these algorithms and did a detailed study comparing the methods used in cloud computing. They shared challenges that have not been solved yet and offered ideas for making the solutions better. The quality of the solutions made by the algorithms depends on how fast they work, how they start out, the methods they use to change things, and how well they keep energy while using a mix of different approaches. Even though the work is about Nature-Inspired algorithms, it doesn't look at how to manage energy in a data center that offers IaaS (Infrastructure as a Service).

Kaur and Chana (2015) studied how to save energy in cloud data centers. The survey looked at different methods suggested to cut down or eliminate power waste in Cloud computing. They looked into moving virtual machines while they are running, using computers with multiple processors, being careful about power and heat, and combining tasks efficiently. The authors say that virtualization is important for managing resources and saving energy in data centers. The survey focused on software solutions that can easily fit into current systems. The authors centered their work on managing resources in a way that saves energy. However, they mainly used heuristic algorithms instead of optimization methods inspired by nature.

Hameed et al. (2014) provide a review and classification of ways to use resources efficiently to save energy. The survey is about managing resources. It talks about using resources that save energy, ways to optimize energy use, and how to distribute those resources. The authors point out difficulties in managing resources by explaining issues with hardware and software methods. They talked about the good and bad aspects of the techniques they looked at and also gave a summary of them. This research only looked at the energy-saving method of distributing resources, which included all types of algorithms. The authors do not talk about Nature-Inspired algorithms that help use resources better and reduce energy use in data centers.

Kołodziej et al. (2012) created a classification of solutions that use ideas from evolution to manage energy in environmentally friendly computing. The paper looked at ideas from nature to help manage energy use, both when things are not changing and when they are, in order to promote environmentally friendly computing. The research looks into how to manage resources in cloud data centers. It includes clear summaries and analysis of different methods that have developed over time. The methods are divided into two types: single-population and multi-population genetic optimization techniques. These methods operate in a changing cloud environment. The writers admit that evolutionary algorithms are not very common compared to other types of algorithms. Many authors have reported that their performance helps reduce the energy used by systems, which is a big step forward for Green computing. The authors looked at the Evolutionary Algorithm, which is based on ideas from nature. We need to look at other nature-inspired methods for managing resources efficiently in data centers.

Beloglazov, et al. (2011) have done detailed studies on ways to make datacenters use energy more efficiently at different levels. The authors above provide a report and classification of power management methods that use hardware and software. However, the basic technology behind cloud computing, called virtualization, hasn't been looked at closely. The authors mainly talk about smart methods that combine physical resources to save energy in data centers. However, the survey does not focus on Nature-Inspired methods.

2.8 Green Cloud Computing

Green cloud computing aims to use computer resources effectively, work more efficiently, and, most importantly, reduce energy use in cloud systems. Energy-saving methods help make the future growth of cloud computing better for the environment. If we do not do this, using many front-end devices with back-end data centers in cloud computing will increase energy use. To solve this problem, we need an energy-saving system to manage resources for using Green cloud computing (Beliga et al., 2010). In order to meet the Quality of Service needs outlined in the Service Level Agreement (SLA) and to reduce power use, efficient resource management should take both into account. Green computing refers to rules and practices that help use computer resources better. This helps to save energy and reduce harm to the environment caused by using a lot of power. Load balancing is one of the best methods to use (Alakeel, 2010; Nakai et al., 2011)

A *Green data center* is a place where computers run efficiently and use less energy. It uses new software to manage how much data is kept, controls power use through agreements and improves performance by using energy-saving equipment. People focus on going green mainly to protect the environment, save energy, and reduce costs. Other reasons for building a green data center include ensuring reliable power and avoiding excessive power use (Uddin et al., 2011). Uddin says that there are several benefits of green data centers, which are listed below (Uddin et al., 2012):

1. Reduce the temperature of servers and storage and lower costs.
2. Make the system and storage more dependable.
3. Get the most out of software and hardware.
4. Improve ways to support the environment and help businesses be more sustainable.
5. Reduce carbon emissions and lessen the impact of global warming.
6. Making the data center last longer.

Iii. Managing Energy In Cloud Computing Data Centers

In managing energy efficiently, it is important to understand the difference between power and energy. It is also important to show how they are connected in the Cloud datacenter. This is because using less power in a computer or its parts doesn't always mean that the total energy used goes down (Knauth, 2014). Power is how fast electricity moves through a circuit, measured in watts. One watt is the same as one joule. In simple terms, power is how electricity is quickly moved or used by a system. On the other hand, energy is the total amount of electricity used over a period of time. Also, power can be thought of as something that changes over time, called P(t), and energy is the total of this power over time, according to Koomey (2008). So, to use less energy, we need to use less power (Knauth, 2014). However, using less power for a short time doesn't always mean that the total energy used by the computers in a data center will go down. This study shows the ways to manage energy at different Cloud data centers in figure 4.

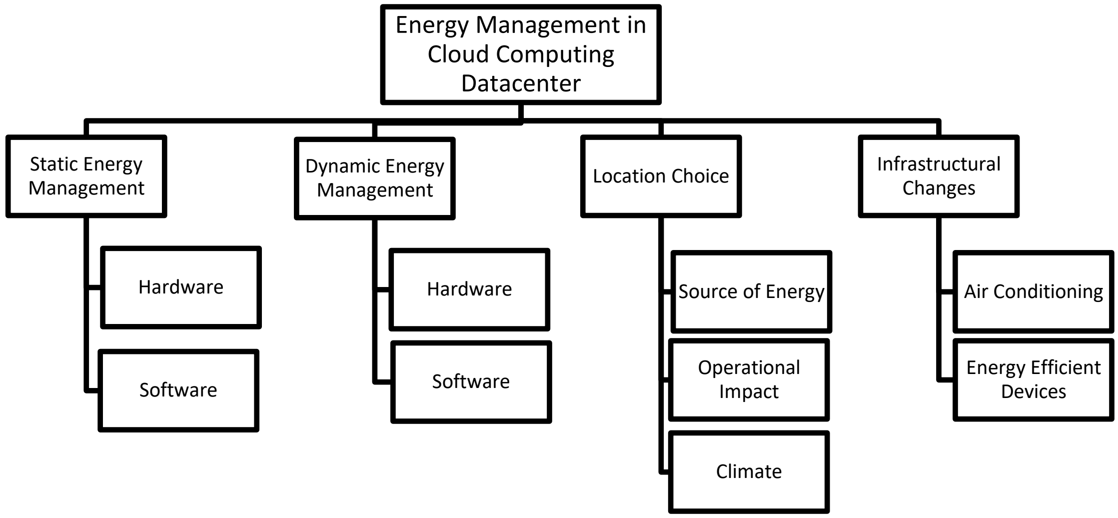

Figure 4: Classification of Energy management in cloud data center

Another part of managing energy for cloud data centers is the difference in energy costs based on location and how clean the energy sources are. Also, where the data center is located, and changes in Infrastructure as a Service (IaaS) are important things to think about when managing how much energy a data center uses. These will be explained briefly in the next paragraph. There are four main types of energy management methods: Static Energy Management (SEM), Dynamic Energy Management (DEM), Location Choices, and Infrastructural Changes (Beloglazov et al., 2012).

1. Static Energy Management (SEM) means using different ways to make energy use better when designing hardware. This usually involves improving the circuits, the logic, and the overall system structure. Even if the hardware is made well, bad software design can cause it to work poorly and waste energy.

2. Dynamic Energy Management (DEM): The techniques used in SEM cannot easily adjust to changes in workload at data centers during operation. The DEM method can be adjusted to different sizes, which helps save energy when using software. This method keeps track of how the system is working and adjusts based on what it needs at the moment. However, DEM needs each part to be adjusted properly, and it is important to understand how these parts work together as a system.

3. Choosing a location: The place where a data center is built matters because these centers produce a lot of heat that needs to be kept cool. The amount of carbon emissions from the data center will depend on the type of energy used in the area where the data center is located. In simple terms, bigger data centers release more carbon because they have more users at the same time, and they cannot easily reduce energy use. Because of these factors, we can say that running tasks in different data centers located in various places can be different. Similarly, climate change can affect the ventilation system that the data center uses. For example, if the data center is in a cold place like Finland or Moscow, it does not need air conditioning. Instead, it can use the cool outside air to keep the equipment cool.

4. Infrastructural Changes: Lastly, updating the equipment to use less energy is another way to manage energy use in the data center. The owners of the data center might choose to update their servers, improve their cooling systems, and switch to better software. These changes can help the data center run more efficiently and use less energy.

5. Using less energy in Cloud data centers makes Cloud Computing more eco-friendly and efficient. In the next sections, we will talk about ways to lower energy use in data centers.

Active versus Idle Low-power-based approach

In this category, data center energy use is reduced in two ways: when it is actively working and when it's not doing much. A device that is turned on does useful work, but if it is not being used, it will go into standby mode. It can also be in a low active state if it is working slowly and using less power compared to when it is fully active. On the other hand, when they are not in use, computer parts do not do any tasks. An example of active power mode is changing the processor speed on its own. During times when demand is low, the frequency can be adjusted to be steady or in specific increments. This is called dynamic voltage frequency scaling (DVFS). This technology, which used to only be found in laptop processors to help save battery life by managing energy use, is now becoming common in new high-performance computing (HPC) systems and servers in cloud data centers. Under DVFS, performance states, known as P-states, determine the speeds at which a processor can run. The Pstates are P0, P1, and P2… Pn, which depends on the processor, can be checked to avoid wasting energy. For example, at P3, a CPU will take more time and use less energy than a CPU at P1 (Snowdon et al., 2005).

Kessaci et al. (2011) introduced a method that helps save energy in data centers. It uses a special computer algorithm along with techniques to lower the power of processors to reduce energy usage. The way we give jobs to processors without breaking the order they need to be done and the method we use for scheduling saves energy. Kliazovich et al. (2013), researchers looked into a method called DVFS to manage resources in data centers. The method looks at how much energy the network and server parts use while also considering the service agreement, traffic needs, and the overall energy use of the data center.

Meisner et al. (2009), this method helps to choose one state instead of many at once, considering factors like how well it works, how long it takes to change, and how much energy it uses. DVFS lowers power use by many watts on one part of a server, which is the CPU (Deng et al., 2011; Sardashti & Wood, 2012). The DVFS technique helps save energy not just for a single server and its parts, but also for the network resources and other communication tools in the data center. This supports green computing (Shojafar et al., 2016). In the same way, Jiang et al. (2016), researchers used the Redundant Links Algorithms (RLA) to find the most important links that were not being used and turned them back on to save energy in the data center. Kim et al. (2011) used a method called power-aware DVFS scaling to save energy in cloud data centers. Some task scheduling methods suggested by Sharma and Reddy (2015) and Yassa et al. (2013) used a technique called DVFS that helps save energy when the power manager is not fully used. Even though this method has improved, the energy use of Cloud data centers has not gone down because it only works for the CPU. So, attention is shifting from physical machines to new methods that data center managers use to improve both the hardware and software used in IaaS.

Energy-aware hardware potential-based approach

In this category, reducing energy is about cutting down power use in parts of a system, like the CPU, memory, disk, and network in cloud data centers. Manufacturers can make them work better by improving the hardware. Many research studies, like those by Gabrel Torres (2015), Snowdon et al.

(2009), Ousterhout et al. (2010), Koomey (2012), Hähnel et al. (2013), Eom et al. (2013), and Jiang et al. (2016), use this method to make their energy use better and improve performance.

Improvement in software development methods

Today, software programs, drivers, and system modules are created with a focus on saving energy. They offer help to users so they can see how the device is working and how much energy it uses (Blanquicet & Christensen, 2008). Michael and Krieger (2010) tested different versions of Windows and Linux by using the same programs on both. They found that the power usage varied significantly between the different versions. An Operating System (OS) is the main software that makes a computer or device work. Different operating systems use different amounts of power, and this can be improved to save energy depending on their type and version (Meisner et al., 2009).

Bringing together IT resources into one approach

Another way to save energy is to combine and share resources like power, memory, disk drives, or CPUs instead of using several of them for each server rack. This method uses less energy in the data center when there are fewer machines being used (Bianzino et al., 2012). Because of this, data center networks have become very important (Nie et al., 2016). This means that tasks from devices that are not being used enough can be sent to other devices to help them work at their best. This is done using a method called minimum criticality technique (Jiang et al., 2016). So, only a few machines are used, which means less energy is used. In the same way, switching from old servers to blade servers, which use about 10% less energy than regular servers, can also help save energy (Power, 2008; Cho & Shin, 2012). In this context, effective consolidation helps to handle the most work using the fewest resources. It also ensures that each resource, like the CPU, disk, or network, is used as much as possible.

IV. Green Cloud Architectural Elements

The goal of this paper is to tackle the issue of using resources in a way that saves energy, which helps create environmentally friendly cloud computing data centers. This will meet the needs of different applications that require computing services while also conserving energy. Figure 5 shows a simple plan for using energy wisely when organizing services in Green Cloud computing. There are four main groups involved:

a) Consumers or brokers can send requests for services to the cloud from any place in the world. It is important to understand that there can be a difference between Cloud customers and the people who use the services that are available. For example, a user can be a company that uses a website. The amount of work the website has to do changes depending on how many people are using it.

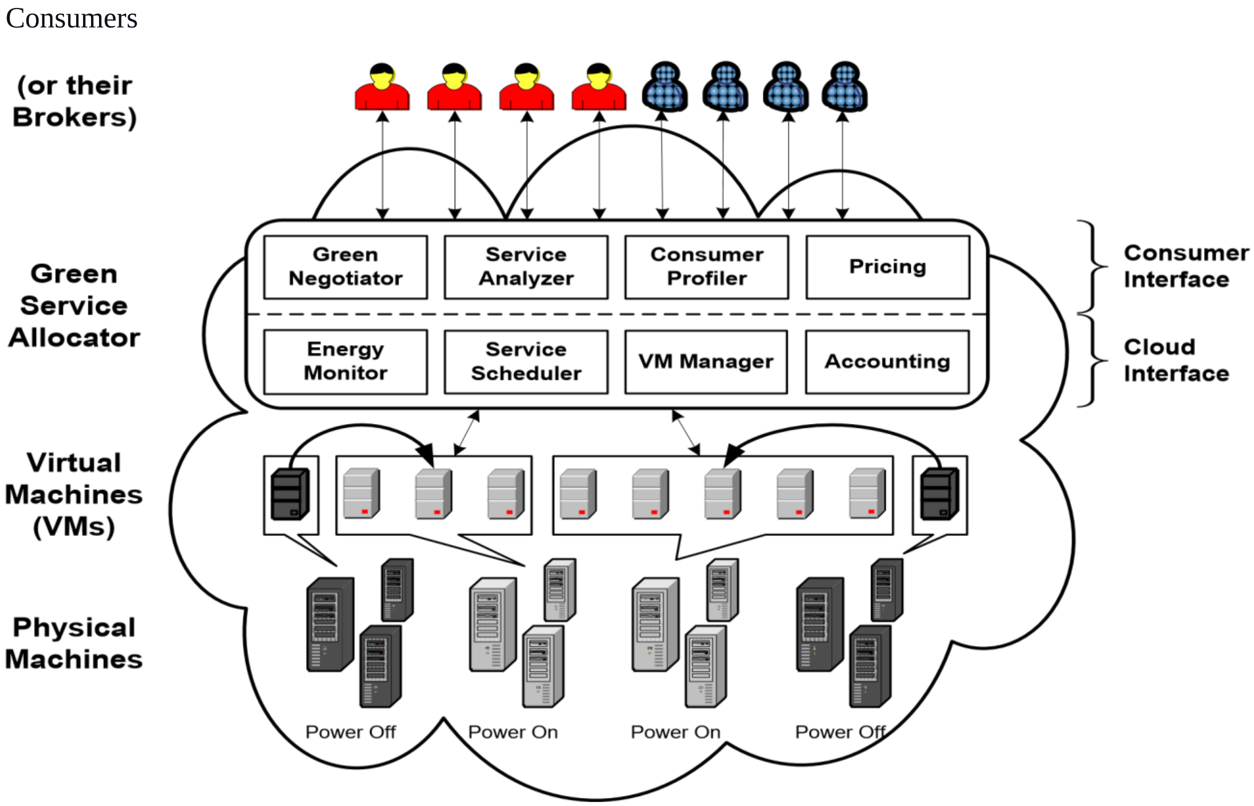

Figure 5: Overall system design layout.

b) Green Resource Allocator: This is the link between the cloud system and the users. To manage resources efficiently and save energy, the following parts need to work together:

- Green Negotiator: Talks with customers and brokers to agree on a Service Level Agreement (SLA) that includes prices and penalties if the agreement is broken. This is based on what the customer needs in terms of service quality and energy savings. For web applications, a quality measurement could be that 95% of requests are handled in under 3 seconds.
- Service Analyser: Looks at and understands the service needs of a request before deciding if it should be accepted or rejected. So, the most recent load and energy details from the VM Manager and Energy Monitor are needed.
- Consumer Profiler: Collects details about customers to identify important ones so they can receive special treatment and be prioritized.
- Pricing: Determines how we charge for service requests to control the use of computing resources and help prioritize service allocation efficiently.
- Energy Monitor: Watches and decides which machines to turn on or off.
- Service Scheduler: It assigns requests to virtual machines (VMs) and decides how many resources each VM can use. It also decides when to add or remove VMs based on needs.

- VM Manager: Watches over the availability of virtual machines (VMs) and what resources they are allowed to use. It also moves virtual machines from one physical computer to another.
- Accounting: Keeps track of how resources are used and calculates the costs based on that usage. Past usage information can help make better decisions about how to distribute services.

c) VMs: You can easily start and stop multiple virtual machines (VMs) on one physical computer to handle requests. This allows you to adjust the resources on that computer to meet different needs for different services. Several virtual machines can run different apps using various operating systems on one physical computer at the same time. Also, by moving virtual machines (VMs) between physical computers as needed, we can group tasks together and save energy by putting unused resources in a low-power mode, turning them off, or setting them to work slower.

d) Physical Machines: The actual computers provide the necessary equipment for creating virtual resources to meet service needs.

Examples of Real Situations

To show how green cloud computing can work in real life, we can look at several examples that showcase the successful methods used by top companies and organizations. These examples show how well energy-saving methods work in real life and give helpful tips for using cloud computing in an eco-friendly way.

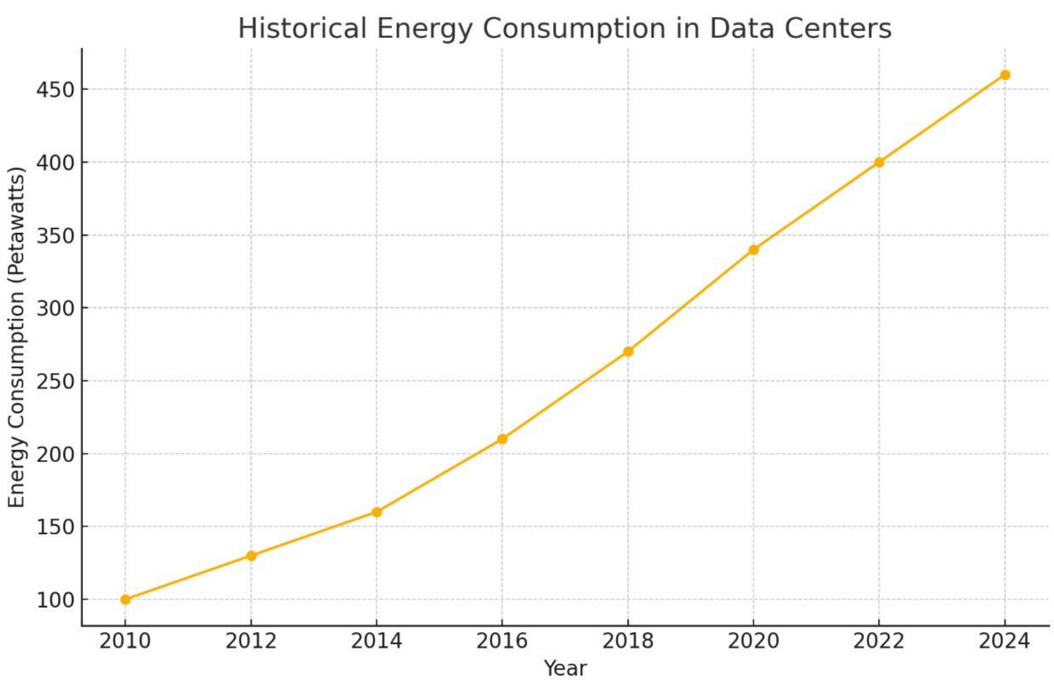

Figure 6: Historical Energy Consumption in Data Centers

Google's Data Centers

Google is a leader in using energy-saving technologies in its data centers. The company has spent a lot of money on renewable energy and smart cooling systems, making its data centers some of the best in the world at saving energy. A report from Google (2017) says that all of Google's data centers have a Power Usage Effectiveness (PUE) of 1.12, which is much better than the industry average of 1.67 PUE is a way to measure how energy-efficient a data center is. A smaller number means it is more efficient.

Google's use of machine learning to improve cooling is especially impressive. Google's AI system looks at past data and current situations to better predict and control cooling needs, which can lower energy use by up to 40%. Also, Google's promise to get all its energy from renewable sources makes its operations more eco-friendly.

Facebook's Open Compute Project

Facebook's Open Compute Project (OCP) is a major effort to make data centers work better. Starting in 2011, OCP worked on creating open-source hardware designs that save energy and are cheaper. Facebook (2019) says that the project has made servers and storage systems that use less energy and produce less heat. This means they need less cooling.

One of OCP's main successes is creating servers that use energy wisely and can easily grow as needed. These servers have been set up in Facebook's data centers, leading to a PUE of 1.06, which is one of the lowest in the industry. Also, OCP's open-source method has allowed other companies to use and change these designs, helping improve energy efficiency in the whole industry.

Microsoft's Project Natick

Microsoft's Project Natick is a new experiment with data centers located underwater. It aims to use the ocean's natural cooling to save energy. Started in 2015, the project aims to put data centers on the ocean floor, where the cool water helps keep them from getting too hot. Microsoft (2018) says that the underwater data center has a PUE of 1.12, which is similar to the best land-based data centers.

Besides being good at cooling, Project Natick is also looking into using renewable energy. The data centers are made to use clean energy from the sea, like wind and tide power, which makes them more eco-friendly. This project shows how new ideas that focus on location can help lower the energy use of data centers.

Alibaba's Data Center in Hangzhou

Alibaba has made important progress in eco-friendly cloud computing with its data center in Hangzhou. This center uses advanced cooling methods and smart technology to manage resources efficiently. Alibaba (2019) says that the data center has a special cooling system that uses fresh air and evaporation to keep cool. This helps use 30% less energy.

Alibaba's data center uses AI to manage resources better and make sure servers work as well as possible in real time. This method has resulted in a PUE of 1.30. While this is not as low as Google's or Facebook's, it is still a big improvement compared to regular data centers. Alibaba's continuous investment in clean energy helps make its cloud services more environmentally friendly.

V. Conclusion

The pressing need for energy-efficient techniques in cloud computing is underscored by the alarming statistics indicating that data centers consume approximately 1.4% of the total energy, with this figure growing by 12% each year. As highlighted throughout this research, the integration of innovative strategies such as virtualization, resource consolidation, and the adoption of renewable energy sources is essential for mitigating the environmental impact of cloud services. Projects like Project Natick and advancements in AI-driven resource management, as seen in Alibaba's data center, demonstrate that it is possible to achieve significant reductions in energy consumption while maintaining performance standards.

Moreover, the challenges associated with implementing sustainable strategies—such as high costs and insufficient collaboration—must be addressed to foster a culture of environmental responsibility within the tech industry. By focusing on creating a balance between energy use and performance, we can ensure that cloud computing continues to provide substantial advantages without compromising our commitment to sustainability. This research not only emphasizes the importance of adopting energy-efficient practices but also serves as a call to action for stakeholders across the industry to prioritize green computing initiatives. Ultimately, the future of cloud technology hinges on our ability to innovate responsibly, ensuring that we meet the demands of today while safeguarding the environment for generations to come.

Future Work

Today, most of the world's energy comes from non-renewable resources like coal. Because there is a limited amount of non-renewable energy, the focus has shifted from trying to lower energy use in data centers. A smart plan that saves energy and can handle a lot of data is now very important. Other important areas need a lot of research to improve energy efficiency in cloud data centers.

In this study, we tried to put together different information about energy-saving systems in one clear image. For green computing, we created four areas: making computers, software plans, educating people, and setting uniform rules. This paper will help all four groups because we showed how ideas for green computing, different methods, and some simple activities in data centers can save energy, time, and money.

Cloud computing is a new way of using technology to make better use of resources and share work more effectively. Our research shows that cloud computing plays a key role in helping the environment. Here are the main points: Cloud technology should be used in a way that causes the least harm to the environment, following green ICT standards. Cloud service companies should use less non-renewable energy and replace it with renewable energy to help protect the environment.

Using more renewable energy would lead to less CO_2 being released into the air. However, since the first step isn't planned yet, it's unlikely that the decrease in pollution from carbon will meet what environmental groups hope for. Both cloud service providers and users should think about using less energy, producing less CO_2, and creating less electronic waste when choosing their services. Cloud computing can help organizations use fewer devices and replace some of their equipment. Cloud service providers should pay attention and adjust their practices to follow the environmental rules in each region.

Groups and non-profit organizations focused on the environment should check and evaluate information about how cloud technology impacts nature. This information can be easily found online and can be helpful in creating new rules to protect the environment. This research is important for people making decisions because it helps them see the need for stronger models for future computing technologies and solutions.

Researchers can use the results of this study to help create new methods because it will give them a clearer understanding of the limits and areas covered in earlier studies on energy efficiency. We also need to create more methods for understanding new trends, like the introduction of 5G technology, artificial intelligence (AI), and edge and fog computing. This paper's findings will help policymakers understand how their energy use could change and encourage them to invest more in energy-saving technologies that lower consumption.

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