Optimizing Data Center Efficiency: Algorithmic Approaches and Simulation Tools for Performance Enhancement

Shivam Arora[1], Dhruv Aswal[2], Aakanshi Gupta[3]
[1,2,3]*Amity School of Engineering and Technology, Amity University, Noida,* Noida, Uttar Pradesh, India

***Abstract*— The increasing demand for cloud computing services has raised concerns about its environmental impact due to high energy consumption. This project explores green computing strategies in cloud data centers to reduce environmental impact while maintaining quality of service. It begins with a comprehensive literature review, focusing on power consumption patterns, hardware performance, virtualization, and workload optimization. The study evaluates energy-efficient technologies, including dynamic resource allocation, power management policies, energy-aware load-balancing Green Algorithms, and advanced cooling. Through simulations and case studies, it measures their impact on energy reduction and operational costs. The study addresses challenges and trade-offs, offering recommendations for sustainable cloud solutions in various scenarios. The results contribute to the field of green cloud computing, promoting an eco-friendly approach to meet computing demands while upholding service standards. we investigate the optimization of data center efficiency through advanced algorithms, leveraging state-of-the-art simulation tools such as OpenDC to analyze and enhance performance metrics."**

Keywords*— *Green Cloud Computing, Data Centers, Energy Efficiency, Sustainability.

I. INTRODUCTION

With an emphasis on technological advancement, computing has quickly changed, especially in the areas of data handling and storage via cloud computing. The potential of cloud computing as an effective and environmentally benign substitute for traditional methods is explored in this study[1], with a focus on its nature-inspired solutions for lessening environmental impact. The main objective is to investigate green algorithms in cloud data centers, with a focus on the advantages of energy management and the mitigation of environmental impact. These algorithms provide encouraging options for effectively managing energy resources, consequently lowering operational costs and environmental impact. Our research covers a wide range of topics in this area, including energy management strategies designed specifically for cloud data centers, creative energy-saving techniques, the creation of energy-efficient measurements, and the use of optimization methods that draw inspiration from nature.

As we investigate the synergy between cloud computing and green algorithms, a central issue is the intricate relationship between technology and environmental stewardship. Our goal is to give academics useful information about energy-saving techniques used in cloud data centers.

A. Approach for Information Retrieval

The method of selecting articles published between 2016 and 2023 by employing the search tools of four scientific databases (IEEE Xplore, MDPI Journals, SpringerLink, and Science Direct) and Google Scholar. In search of relevant articles, a combination of keywords in various forms with 'OR' and ('AND' or '+') operators. (Green OR Sustainable) AND "Cloud Computing") OR (Energy AND (efficient OR consumption) AND methods) OR (("Carbon footprint" OR "Renewable Energy") AND "Data Center")

A first search on Google Scholar was undertaken to gain an understanding of the topic and to locate key scholarly databases that address it. The information or papers were then retrieved by conducting a search on those major scientific databases.

a) Study Selection

The lookup began with a simple search that yielded 2063 publications. Duplicate papers were removed, journal titles and abstracts were evaluated for importance, and each paper's abstract was thoroughly examined, including data extraction, to ensure compliance with the inclusion criteria. Following the completion of the filtration procedure based on the defined inclusion and exclusion criteria, a total of 41 papers were maintained since they matched the research requirements effortlessly. Following in-depth reading and analysis, these 41 publications were turned into a full corpus.

b) Criteria for Inclusion

When selecting and going through a corpus for a research paper on "Green Cloud Computing and Sustainable Techniques," it's important to establish clear criteria for inclusion to ensure the relevance and quality of the sources.

- *Relevance to Green Cloud Computing:*
  - Inclusion Criterion: Sources should directly relate to green cloud computing, its environmental impact, sustainability, and associated technologies or practices.
- *Recent and Updated Information:*
  - Inclusion Criterion: Preference should be given to recent sources (typically within the last 5-10 years) to ensure the information is current and reflective of the latest developments in the field.
- *Credibility and Authoritativeness:*
  - Inclusion Criterion: Sources must be from reputable and recognized sources, such as peer-reviewed journals, academic institutions, governmental bodies, and well-established organizations. Consider the author's expertise in the field.
- *Objectivity and Lack of Bias:*
  - Inclusion Criterion: Sources should present information objectively, avoiding bias, commercial interests, or conflicts of interest that could compromise the integrity of the research.

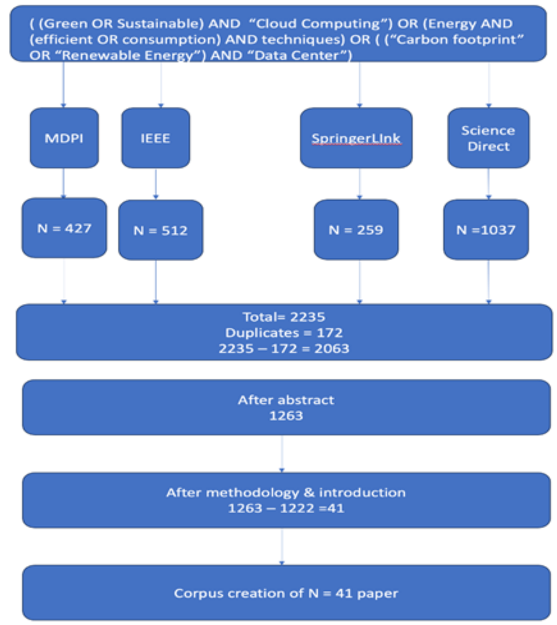

Fig 1- Study Selection

B. Overview

With a primary focus on sustainability and cost-effectiveness, this paper conducts an in-depth exploration of energy-efficient, green approaches utilized in cloud data centers. We proceed cautiously, recognizing the benefits and complexities of these methods. It is crucial to emphasize that these techniques show promise in lowering energy use and minimizing carbon emissions; however, in order to fully realize this potential, a thorough assessment is necessary. Our main goal is to investigate green algorithms in the context of cloud computing, with a focus on power management. This is the core of our study. We cover a wide range of topics in this in-depth analysis, including energy-saving tactics, conservation methods, and optimization strategies. Our purpose is to be the guiding light for the researchers and practitioners, supporting them as they work to integrate green algorithms into cloud computing. As we conclude this section, it is critical to emphasize the far-reaching consequences of our findings. Our research aims to shed light on the potential for energy conservation within cloud data center architecture. We hope to be a useful resource for academics, professionals, and legislators, contributing to the ongoing discussion about energy efficiency in cloud data center infrastructure. Our vision extends beyond the near horizon, imagining a digital future in which the tremendous potential of cloud computing seamlessly aligns with natural wisdom, ushering in a more sustainable and intelligent digital world.

II. EFFECT ON DATA CENTERS

Energy efficiency is a major concern for cloud data centers. In the digital age, data has become the lifeblood of businesses and individuals, and the demand for cloud data centers is increasing. These data centers are the backbone of our connected world; It hosts and processes vast amounts of information and powers everything from e-commerce platforms to social media networks. However, as the demand for data storage and processing continues to increase, the power consumption of these data centers also increases. Power consumption is now a major issue in cloud data centers and one that cannot be ignored.

A. Strong Growth

Statistics are disappointing. The usage of fossil fuels in the electrical sector is the largest contributor to the CO_2 emissions associated with data center operations. More than 2% of the world's total CO_2 emissions in 2014 were predicted to come from data centers, which produced 200 million tonnes of CO_2. Data center-related CO_2 emissions are expected to surpass 14% of worldwide CO_2 emissions in 2040 by then. [2] This increase in energy use is largely due to the ongoing requirement for data processing, storage, and cooling within these facilities. Data center servers run continuously, generating significant heat that must be handled by energy-intensive cooling systems to avoid overheating and equipment failure. This surge in energy usage is largely driven by the proliferation of cloud computing, with data centers working around the clock to meet the demands of businesses and consumers for seamless access to their data. [3][4].

B. The Environmental Impact

Data centers have a significant environmental impact, primarily due to their energy consumption, carbon emissions, and resource usage. Here are some key environmental impacts of data centers;

Energy Consumption: Data centers are energy-intensive buildings that need a lot of electricity to run. They contain several servers, networking hardware, and cooling systems that are active around-the-clock. The depletion of fossil fuels and the release of greenhouse gases are both impacted by this high energy demand.

Carbon emissions: Coal and natural gas are two common fossil fuels used to provide the electricity needed to run data centers. These fuels are burned, and the resulting emissions of carbon dioxide (CO_2) and other greenhouse gases into the atmosphere cause climate change. A sizable fraction of the world's carbon emissions are caused by data centers. Data centers emit a substantial amount of carbon dioxide (CO_2) into the atmosphere, contributing to climate change. [5]

Heat generation: Data centers produce a significant quantity of heat as a result of the constant use of servers and other hardware. To get rid of this heat, cooling systems are required, and they need more energy. Particularly in urban locations with a large concentration of data centers, the heat produced can potentially have an impact on regional microclimates.

Water Consumption: Some data centers consume a lot of water to cool down, especially in areas with warm weather. In many regions of the world, there is an increasing concern about water scarcity, which may be made worse by data centers' high water consumption.

Resource Depletion: To manufacture and dispose of electronic equipment, such as servers and networking hardware, raw materials must be extracted and energy-intensive manufacturing methods must be used. [6-10]

C. The Role Of Cloud Computing

When cloud data centers are part of energy problems, it is also important to solve them. If cloud computing is used effectively, data center energy consumption can be reduced. The process is as follows:

a) Server Virtualization and Resource Consolidation

Server virtualization technology, which enables several virtual servers to run on a single physical server, is being used more and more by cloud service providers. With this strategy, fewer actual servers are needed, which results in significant energy savings. Although the precise proportion of savings can vary depending on particular configurations and conditions, studies have shown that server virtualization can result in significant reductions in energy use. A study from the U.S. Department of Energy found that server virtualization can reduce energy consumption by up to 50%. [11-13]

b) Dynamic Resource Management and Renewable Energy Integration

Platforms for cloud computing are excellent at dynamically distributing computing resources according to demand, enabling servers to shut down or go into low-power modes during times of low utilization. In order to sustainably power their data centers, top cloud providers like Google are also making significant investments in renewable energy sources like solar and wind power. These programs highlight the viability, advantages, and benefits of switching to renewable energy sources while minimizing environmental effects.[14]

c) Innovative Cooling Solutions and Energy-Efficient Hardware

A significant portion of the energy used in data centers goes toward cooling. Cloud service companies are aggressively investigating cutting-edge cooling technologies, such as Microsoft's Project Natick, which submerges data centers in the ocean to make use of the cooling capabilities of natural water. The overall objective of lowering energy consumption and boosting sustainability in data center operations is furthered by these coordinated initiatives. [15]

- *Cooling control optimization using a deep reinforcement learning-based approach*

Deep reinforcement learning, a type of machine learning that includes teaching an agent to make decisions based on rewards and penalties received from the environment, is the foundation of the suggested approach for cooling management optimization in data centers. The actor-critic deep deterministic policy gradient (DDPG) algorithm, a form that uses two neural networks to approximate the policy and the value function, is the algorithm utilized in this approach. It is an off-policy offline variation of the DDPG algorithm. Both a simulation example and a real data trail obtained from Singapore's National Super Computing Centre (NSCC) are used to evaluate the approach. The findings demonstrate that the suggested algorithm may significantly reduce power use effectiveness (PUE) and keep the data center's temperature within a specified range. [16].

III. ENERGY EFFICIENT TECHNIQUES

A. Task scheduling

A major component of encouraging green cloud computing in data centers is effective task scheduling. Its contributions cover a wide range of topics. For starters, it improves energy efficiency by intelligently assigning work duties to servers, lowering the number of active servers during low-demand periods, and allowing them to go idle or shut down, thus saving energy. Second, load balancing ensures that workloads are dispersed uniformly across servers, preventing server hotspots and the related high power consumption, as well as reducing the requirement for overprovisioning. Furthermore, task scheduling provides dynamic resource allocation, which optimizes the usage of resources such as CPU, memory, and storage, preventing waste and increasing energy efficiency. Furthermore, by scheduling peak work during periods of peak renewable energy generation, it promotes the incorporation of renewable energy sources such as wind or solar power, lowering dependency on fossil fuels and data center carbon footprints. Task scheduling can also be integrated with cooling operations, resulting in lower cooling air consumption and improved green computing. Finally, it enables the tracking of green metrics such as Energy Use Effectiveness (PUE) and Carbon Use Effectiveness (CUE), which aids in making educated decisions about resource allocation and energy-saving initiatives. [9].

B. Dynamic voltage and frequency scaling (DVFS)

Adjusting the voltage and frequency of the processors based on the workload to reduce energy consumption. Dynamic voltage and frequency scaling (DVFS) modifies the power and speed settings on a computer's different CPUs, controller chips, and peripheral devices to maximize power savings when those resources are not required. Dynamic Voltage and Frequency Scaling (DVFS) is a power-saving technique used in data centers and other computing environments to improve performance and power consumption and help reduce energy consumption and energy production. DVFS works by dynamically adjusting the processor's voltage and clock frequency based on the processor's current workload and performance requirements. Here is how DVFS works in data centres:

a) Voltage and Frequency Scaling:

In DVFS, the operating voltage and clock frequency of the processor are adjusted on the fly to meet the needs of the job. When the office is light or inactive, the voltage and frequency can be reduced to save energy. Conversely, the voltage and frequency can be increased to ensure good performance when working hard.

b) Power and Performance Trade-offs:

DVFS takes advantage of the power and performance trade-offs inherent in semiconductor devices. Reducing the voltage and frequency may reduce power consumption, but may also reduce the performance of the processor. Conversely, increasing the voltage and frequency may improve performance but result in higher power consumption.

c) Dynamic response:

DVFS is dynamic and can respond to changing workloads. It constantly monitors processor usage and adjusts it when necessary. For example, in cases where demand is high, voltage and frequency are increased to provide the required operating power. When demand decreases, they are reduced to save electricity. [18-23]

C. Power Capping

Power capping is the process of setting and dynamically modifying power restrictions for hardware components in order to optimize energy consumption, save expenses, and improve data center efficiency. Administrators set power limitations for individual servers, server racks, or the entire data center, either in watts or as a percentage of maximum power use. These constraints change in response to changing workloads and environmental circumstances. The system constantly analyzes energy use and takes action if it approaches the limit, such as temporarily shutting down the CPU or lowering the clock speed. Power capping decreases waste lowers cooling requirements, and aids load balancing for optimal job allocation, especially in large data centers. [24][25]

D. Energy-Aware Scheduling (EAS)

Scheduling jobs based on their power requirements and the available power budget. Energy-aware scheduling (or EAS) gives the scheduler the ability to predict the impact of its decisions on the energy consumed by CPUs. EAS relies on an Energy Model (EM) of the CPUs to select an energy-efficient CPU for each task, with a minimal impact on throughput. EAS focuses on scheduling decisions while considering the performance of hardware components such as processors and cores. The main purpose of time awareness is to reduce data center usage without degrading performance or violating technical-level recommendations. From flexible switching to resilient switching and taking advantage of the different power capabilities of the hardware, EAS helps increase the overall power and stability of the data office. It is an important part of a green computing strategy that helps data centers reduce their carbon footprint and operating costs. [24-27]

E. Resource Orchestration and Green Architecture

DM bui et al. (2017), proposed an approach that employs methods like convex optimization and Gaussian process regression to efficiently manage resources in data servers. It aids in effectively allocating the appropriate number of real servers and managing virtual machines. By ensuring that data servers operate at optimal resource levels, energy usage is decreased. [29]

Client-oriented green cloud middleware is one example of a green architecture that helps with energy-efficient decision-making. They aid in selecting the routes that use the least amount of energy, in making the best use of available resources, and perhaps even in moving workloads to periods when renewable energy sources are available. This synchronizes the functioning of data servers with the accessibility of renewable energy sources. [30]

F. Low-Power Processor: Intel Xeon

A study conducted by National Institute for Research and Development in Informatics, The findings demonstrated that for all workloads, systems powered by Intel Xeon Platinum 8180 and 8280 processors used the most power. For all forms of workload loading, computers with Intel Xeon Platinum 8276L processors utilized the least amount of electricity. Systems using Intel Xeon Platinum 8176 processors used more power than those with Xeon Platinum 8280L processors for workloads of 100%, 90%, and 80%; however, for smaller workloads, the power consumption was nearly similar. [31-33].

IV. GREEN ALGORITHMS

The Green Algorithms algorithm is a methodological framework that consistently and accurately calculates the carbon footprint of each computational job. The technique divides an algorithm's carbon footprint into a few essential, readily quantifiable components, such as the number of cores, memory size, and usage factor. The algorithm considers the runtime, the location of the data center, and the tool's hardware requirements when estimating a computation's carbon footprint. Additionally, it employs a pragmatic scaling factor (PSF) to permit empirical estimations of repeated computations for a specific job, such as parameter tuning and trial-and-error experiments. [34][35]

Panwar et al. (2022), gave different approaches to optimized energy namely heuristic, metaheuristic technique, machine learning, and statistical techniques. When compared to the current approaches, experts have found that the heuristic approach can save anywhere between 5.4% and 90% of energy. Metaheuristic methods can be used to regulate energy usage in cloud data centers in a way that maximizes resource allocation and uses less energy. Particle Swarm Optimization (PSO) and Genetic Algorithm (GA) are two examples .of metaheuristic methods [36]

A. CEEST Algorithm

The CEEST algorithm is a green cloud computing algorithm that manages and optimizes servers in data centers by making the most use of their resources and turning off any servers that aren't being used. The quality of service (QoS) is not compromised while the energy usage is decreased. The technique makes use of virtual machine scaling to complete tasks by the deadlines in order to decrease service level agreement (SLA) violations. By scheduling virtual machines and duties to other available servers and shutting down idle or underused servers, CEEST improves server resource usage. CEEST performs better in terms of energy usage because if a server is not being used, the optimization process shuts it down, saving a substantial amount of energy. The proposed algorithm saves energy up to 30% in comparison to existing algorithms. [37][38].

B. Energy Consumption Optimization Algorithms

Kar et al. (2022) from IEEE suggested a few energy consumption methods employed in cloud computing differ based on the research's specific setting and goals. However, Lyapunov optimization, simulated annealing, and branch and bound algorithms are some frequently used techniques for energy usage optimization in cloud computing. These algorithms are employed in cloud-edge-fog systems to maximize the trade-off between energy usage and other performance parameters, such as response time and latency. In dynamic contexts with a lot of unknowable information, other machine learning-based approaches, such as reinforcement learning, have also been suggested for energy usage optimization. [39]

C. Energy and carbon-aware algorithm for virtual machine placement

Zhao et al. (2022), proposed an algorithm for virtual machine placement that optimizes the distribution of virtual machines based on the accessibility of renewable energy sources and the carbon footprint of energy use, thereby reducing energy consumption in geographically dispersed data centers. The system accomplishes this by modifying workload distribution and virtual machine placement dynamically to maximize the use of renewable energy sources while reducing the carbon footprint of energy use. The algorithm decreases dependency on conventional power networks by increasing the utilization of renewable energy, which can result in substantial energy and cost savings. The experimental findings displayed in the paper demonstrate that the suggested strategy is more environmentally friendly and energy-efficient, and that it can also maximize the usage of renewable energy sources with 73.11%. [40]

D. HUNTER Algorithm

HUNTER is a holistic resource management method for sustainable cloud computing that is AI-based. By taking into account three significant models—energy, thermal, and cooling—it formulates the purpose of optimizing energy efficiency in data centers as a multi-objective scheduling problem. For determining the best scheduling choices and approximating the Quality of Service (QoS) for a system state, HUNTER uses a Gated Graph Convolution Network (GGCN) as a substitute model. By using the GGCN-based deep surrogate model, HUNTER may generate QoS estimations rapidly and without incurring major costs for evaluating different scheduling strategies. In order to efficiently balance the load on cloud hosts, HUNTER employs performance-to-power ratio as a heuristic, providing maximum computational power while lowering energy usage. In the majority of QoS measures, HUNTER surpasses current AI-based resource schedulers (HDIC, SDAE-MMQ, ANN, and PADQN) as well as heuristic algorithm-based resource schedulers (CRUZE and MITEC). Furthermore, HUNTER provides the best energy consumption, SLA violation, cost, and temperature results by up to 12%, 35%, and 54%, respectively, with 42.78% less scheduling overheads than the best baseline. Therefore, HUNTER seems to be a better strategy for energy-efficient cloud resource management than conventional heuristics and algorithms based on reinforcement learning.

V. SIMULATOR

Powerful simulations, cutting-edge technology, and applications for modern datacenters have already been developed by the community. Here, we're attempting a new approach with OpenDC, an open-source simulator. OpenDC is a datacenter simulation platform that allows users to model and simulate many features of modern datacenters. It uses discrete-event simulation to study how datacenter components operate over time, such as resource allocation, workload scheduling, and performance indicators. OpenDC includes prefabs for quick replication and scaling of datacenter designs, serverless computing simulation, TensorFlow-based machine learning, interactive experimentation via a web interface, experiment automation, and a library of prefabs for sharing datacenter designs. Overall, OpenDC makes it easier to experiment with emerging technologies like serverless computing and machine learning in datacenter environments.[41]

VI. CONCLUSION

In conclusion, the various research studies and papers discussed highlight the significance of "green cloud computing" and the pursuit of energy efficiency in data centers. They emphasize the potential benefits of environmentally friendly cloud computing, such as reduced carbon emissions, cost-effectiveness, and efficient resource management. However, these studies also acknowledge the challenges and limitations in implementing green cloud computing, underscoring the necessity for ongoing research to address these issues and develop holistic strategies for sustainability. Collaboration between stakeholders, including ICT equipment producers, service providers, and non-governmental organizations, is crucial to mitigate the environmental impact of hardware and software. Additionally, the studies offer valuable insights and future research directions to optimize different aspects of cloud computing, making it more environmentally sustainable and energy-efficient. These findings underscore the imperative of balancing energy consumption across processing, storage, and transport in order to realize the full potential of green cloud computing and contribute to a more sustainable and eco-friendly digital future. [42]

Simulation is crucial for developing and implementing innovative strategies in datacenter operations. Simulators such as Grid/CloudSim [43], SimGrid [44], and iCanCloud [45] have proved their capacity to depict and understand very complex operations at the cluster and datacenter levels. The availability of OpenDC as open-source software increases its value to the research community by allowing for cooperation, experimentation, and innovation in the field of datacenter simulation. Researchers can use platforms like OpenDC to better understand datacenter operations, build efficient architecture, and contribute to the training of future datacenter specialists.

REFERENCES

[1] Usman, Mohammed Joda, et al. "Energy-efficient nature-inspired techniques in cloud computing datacenters." *Telecommunication Systems* 71 (2019): 275-302.

[2] Belkhir, Lotfi, and Ahmed Elmeligi. "Assessing ICT global emissions footprint: Trends to 2040 & recommendations." *Journal of cleaner production* 177 (2018): 448-463.

[3] IRadu, Laura-Diana. "Green cloud computing: A literature survey." *Symmetry* 9.12 (2017): 295.

[4] Dalenogare, Lucas Santos, et al. "The expected contribution of Industry 4.0 technologies for industrial performance." *International Journal of production economics* 204 (2018): 383-394.

[5] Singh, Manmeet, et al. "Dynamic shift from cloud computing to industry 4.0: Eco-friendly choice or climate change threat." *IoT-based Intelligent Modelling for Environmental and Ecological Engineering: IoT Next Generation EcoAgro Systems*. Cham: Springer International Publishing, 2021. 275-293.

[6] Alarifi, Abdulaziz, et al. "Energy-efficient hybrid framework for green cloud computing." *IEEE Access* 8 (2020): 115356-115369

[7] Baliga, Jayant, et al. "Green cloud computing: Balancing energy in processing, storage, and transport." *Proceedings of the IEEE* 99.1 (2010): 149-167.

[8] Rong, Huigui, et al. "Optimizing energy consumption for data centers." *Renewable and Sustainable Energy Reviews* 58 (2016): 674-691.

[9] Jing, Si-Yuan, et al. "State-of-the-art research study for green cloud computing." *The Journal of Supercomputing* 65 (2013): 445-468.

[10] Xiong, Naixue, Wenlin Han, and Art Vandenberg. "Green cloud computing schemes based on networks: a survey." *Iet Communications* 6.18 (2012): 3294-3300.

[11] Kumar, Pasupuleti Venkata Siva, and Myelinda Baldelovar. "Green Cloud Computing and Its Role in Reducing Carbon Footprint."

[12] Rahman, Altaf Ur, Fiaz Gul Khan, and Waqas Jadoon. "Energy efficiency techniques in cloud computing." *International Journal of Computer Science and Information Security (IJCSIS)* 14.6 (2016).

[13] Bindhu, V., and M. Joe. "Green cloud computing solution for operational cost efficiency and environmental impact reduction." *Journal of ISMAC* 1.02 (2019): 120-128.

[14] Jin, Xibo, et al. "Green data centers: A survey, perspectives, and future directions." *arXiv preprint arXiv:1608.00687* (2016).

[15] Katal, Avita, Susheela Dahiya, and Tanupriya Choudhury. "Energy efficiency in cloud computing data centers: a survey on software technologies." *Cluster Computing* 26.3 (2023): 1845-1875.

[16] Li, Yuanlong, et al. "Transforming cooling optimization for green data center via deep reinforcement learning." *IEEE transactions on cybernetics* 50.5 (2019): 2002-2013.

[17] Valentini, Giorgio Luigi, et al. "An overview of energy efficiency techniques in cluster computing systems." *Cluster Computing*16 (2013): 3-15.

[18] Usman, Mohammed Joda, et al. "Energy-efficient nature-inspired techniques in cloud computing datacenters." *Telecommunication Systems* 71 (2019): 275-302.

[19] Bui, Dinh-Mao, et al. "Energy efficiency for cloud computing system based on predictive optimization." *Journal of Parallel and Distributed Computing* 102 (2017): 103-114.

[20] Ilager, Shashikant. *Machine Learning-based Energy and Thermal Efficient Resource Management Algorithms for Cloud Data Centres*. Diss. University of Melbourne, 2021.

[21] Panwar, Suraj Singh, Man Mohan Singh Rauthan, and Varun Barthwal. "A systematic review on effective energy utilization management strategies in cloud data centers." *Journal of Cloud Computing* 11.1 (2022): 95.

[22] Ajmal, Muhammad Sohaib, et al. "Cost-based energy efficient scheduling technique for dynamic voltage and frequency scaling system in cloud computing." *Sustainable Energy Technologies and Assessments* 45 (2021): 101210.

[23] Rahman, Altaf Ur, Fiaz Gul Khan, and Waqas Jadoon. "Energy efficiency techniques in cloud computing." *International Journal of Computer Science and Information Security (IJCSIS)* 14.6 (2016).

[24] Alarifi, Abdulaziz, et al. "Energy-efficient hybrid framework for green cloud computing." *IEEE Access* 8 (2020): 115356-115369.

[25] Ramesh, Srinivasan, et al. "Understanding the impact of dynamic power capping on application progress." *2019 IEEE International Parallel and Distributed Processing Symposium (IPDPS)*. IEEE, 2019.

[26] Haidar, Azzam, et al. "Investigating power capping toward energy-efficient scientific applications." *Concurrency and Computation: Practice and Experience* 31.6 (2019): e4485.

[27] Borghesi, Andrea, et al. "Scheduling-based power capping in high performance computing systems." *Sustainable Computing: Informatics and Systems* 19 (2018): 1-13.

[28] Bui, Dinh-Mao, et al. "Energy efficiency for cloud computing system based on predictive optimization." *Journal of Parallel and Distributed Computing* 102 (2017): 103-114.

[29] Bui, Dinh-Mao, et al. "Energy efficiency for cloud computing system based on predictive optimization." *Journal of Parallel and Distributed Computing* 102 (2017): 103-114.

[30] Jin, Xibo, et al. "Green data centers: A survey, perspectives, and future directions." *arXiv preprint arXiv:1608.00687* (2016).

[31] Rădulescu, Constanţa Zoie, and Delia Mihaela Rădulescu. "A performance and power consumption analysis based on processor power

models." *2020 12th International Conference on Electronics, Computers and Artificial Intelligence (ECAI)*. IEEE, 2020.

[32] Szustak, Lukasz, et al. "Correlation of performance optimizations and energy consumption for stencil-based application on Intel Xeon scalable processors." *IEEE Transactions on Parallel and Distributed Systems* 31.11 (2020): 2582-2593.

[33] Sodani, Avinash, et al. "Knights landing: Second-generation intel xeon phi product." *Ieee micro* 36.2 (2016): 34-46.

[34] Lannelongue, Loïc, Jason Grealey, and Michael Inouye. "Green algorithms: quantifying the carbon footprint of computation." *Advanced science* 8.12 (2021): 2100707.

[35] Wu, Xiuli, and Yangjun Sun. "A green scheduling algorithm for flexible job shop with energy-saving measures." *Journal of cleaner production* 172 (2018): 3249-3264.

[36] Panwar, Suraj Singh, Man Mohan Singh Rauthan, and Varun Barthwal. "A systematic review on effective energy utilization management strategies in cloud data centers." *Journal of Cloud Computing* 11.1 (2022): 95.

[37] Ajmal, Muhammad Sohaib, et al. "Cost-based energy efficient scheduling technique for dynamic voltage and frequency scaling system in cloud computing." *Sustainable Energy Technologies and Assessments* 45 (2021): 101210.

[38] Mahendran, Rakesh Kumar, et al. "An energy-efficient centralized dynamic time scheduling for internet of healthcare things." *Measurement* 186 (2021): 110230.

[39] Kar, Binayak, et al. "A survey on offloading in federated cloud-edge-fog systems with traditional optimization and machine learning." *arXiv preprint arXiv:2202.10628* (2022).

[40] Zhao, Daming, and Jiantao Zhou. "An energy and carbon-aware algorithm for renewable energy usage maximization in distributed cloud data centers." *Journal of Parallel and Distributed Computing* 165 (2022): 156-166.

[41] Mastenbroek, Fabian, et al. "OpenDC 2.0: Convenient modeling and simulation of emerging technologies in cloud datacenters." *2021 IEEE/ACM 21st International Symposium on Cluster, Cloud and Internet Computing (CCGrid)*. IEEE, 2021.

[42] Tuli, Shreshth, et al. "HUNTER: AI based holistic resource management for sustainable cloud computing." *Journal of Systems and Software* 184 (2022): 111124.

[43] Calheiros, Rodrigo N., et al. "CloudSim: a toolkit for modeling and simulation of cloud computing environments and evaluation of resource provisioning algorithms." *Software: Practice and experience* 41.1 (2011): 23-50.

[44] Casanova, Henri, et al. "Versatile, scalable, and accurate simulation of distributed applications and platforms." *Journal of Parallel and Distributed Computing* 74.10 (2014): 2899-2917.

[45] Núñez, Alberto, et al. "iCanCloud: A flexible and scalable cloud infrastructure simulator." *Journal of Grid Computing* 10 (2012): 185-209.