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Original Article

Green Computing – A Survey of the Current Technologies

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Abstract

Cloud computing is a dynamic technology with various application spheres because of its scalability, cost-effectiveness, and reliability. However, since the energy demand for information and Communication Technologies (ICT) is on the rise, cloud computing is facing new challenges related to environmental protection, power consumption, energy efficiency, and carbon dioxide emissions. The latest technologies that strive for sustainable energy efficiency and a reduced e-waste and carbon footprint are constantly being researched and deployed. These technologies have the potential to transform cloud computing into green cloud computing. In this survey, the authors investigated recent research methodologies such as algorithm-based, architecture-based, framework-based, model-based, methods-based, and general issue-based approaches. Many of these research projects are still in their infancy and are yet to be commercially implemented. The last thing that was talked about was some future research trends and some of the open challenges in green cloud computing.

Keywords: Cloud Computing; Green Cloud Computing; ICT; E-waste; Carbon Footprint

Introduction

A. Green Computing

It has been found that approximately 24 million computers are discarded. Only 14% of these are recycled, and the rest are destroyed as waste products. Most of this e-waste is dumped in developing countries. The burning of these wastes creates a type of acid and another chemical waste that ultimately ends up in the river, polluting the water and harming the aquatic life. These eventually end up in our food system and do irreversible health damage. The International Telecommunication Union (ITU) published a report that e-waste is increasing rapidly in different continents and has reached a global high. E-waste production continent-wise is shown in Figure 1.

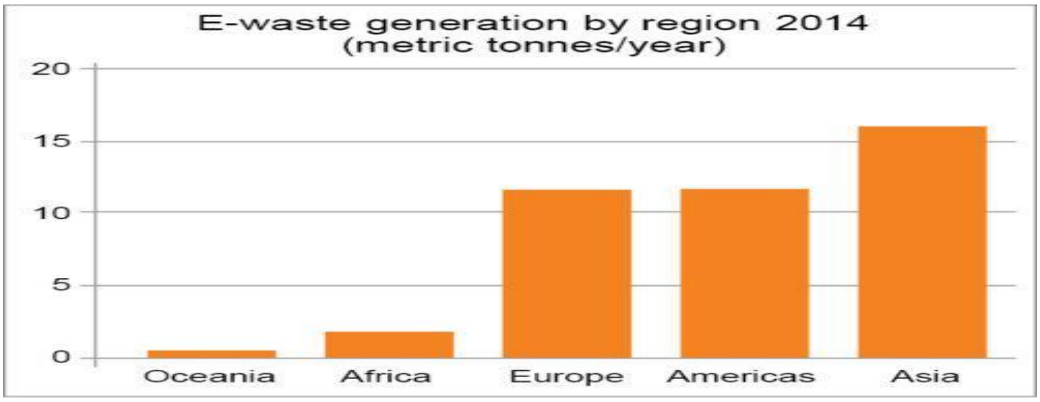

Figure 1: Worldwide e-waste generation graph (Baldé *et al.*, 2017)

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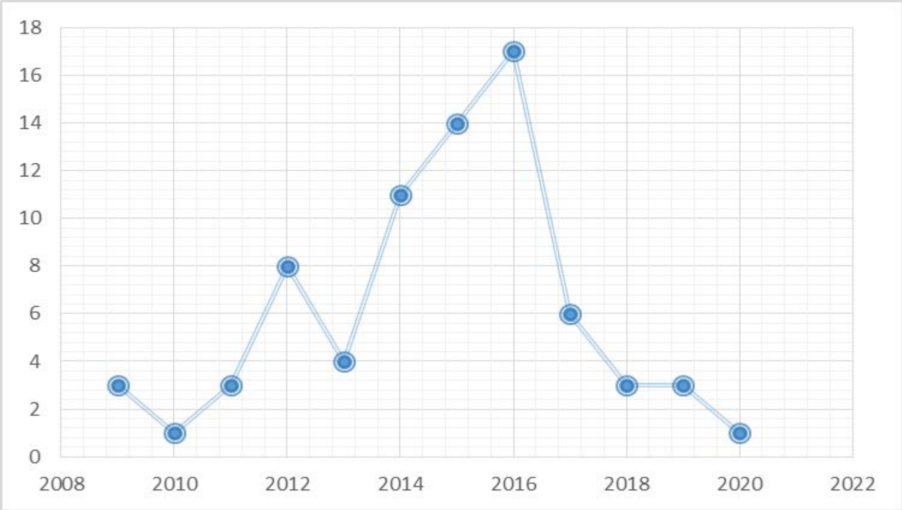

Figure 4: Distribution of the primary study year-wise

Table 3: Outline of the selection process

Step	Articles Rejected	Articles Remained
Primary Search	×	108
Title check	9	99
Abstract check	17	82
Full Article	16	66

Research Trends in Green Cloud Computing

Gartner reported that ICT industries worldwide contributed to 2% of the carbon dioxide emission. Liu *et al*. (2009) had proposed the Green Cloud architecture in 2009 to reduce the energy consumption by the data centers. The research works based on green cloud computing and green computing as a whole gained momentum since 2009. Figure 5 shows the number of published works since 2009 in different categories and the different environmental issues addressed in these papers are shown graphically in Figure 6.

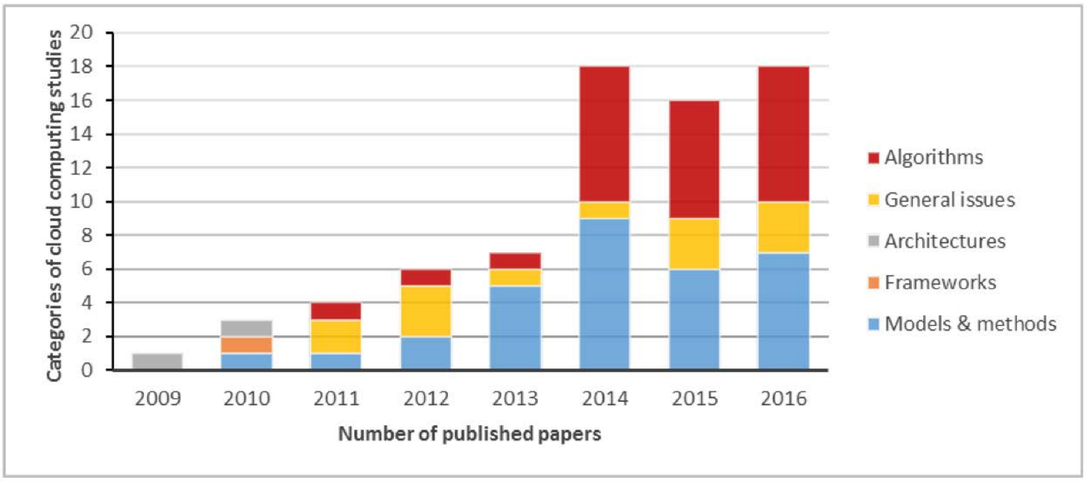

Figure 5: Different approaches in the green cloud computing-based research (Radu, 2017)

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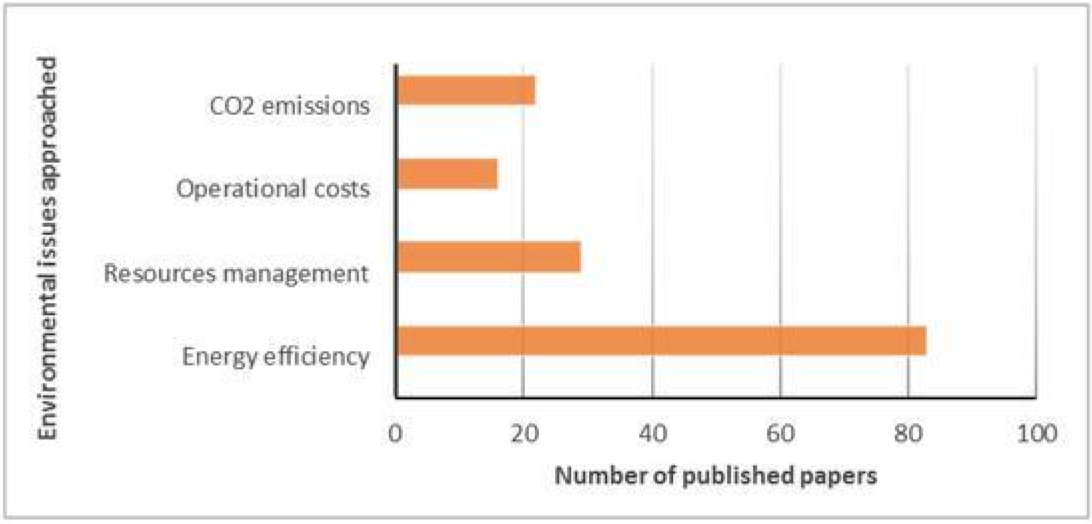

Figure 6: Various environmental issues addressed by these research works (Radu, 2017)

Research on green cloud computing can be divided into five different fields of studies – models and methods, architecture, frameworks, algorithms, and general issues. These research proposals focused on issues related to improvement in energy efficiency, reduction in operational cost, efficient management of hardware and software resources of data centers, and reduction in e-waste and carbon dioxide emission.

A. Algorithm Based Approach

To handle the power consumption problems related to Internet services, dynamic allocation of servers has proved to be an effective method to turn off servers not in use. Yang *et al.* (2011) proposed greening the power management (GPM) of physical machines using virtualization technology and achieved a substantial improvement over the traditional method. Logical separation of the service from the physical resources allows the system to run the operating system and the applications in an environment that is separate from the physical system.

Virtual machines (VM) are allocated on demand for a short interval of time, thus requiring them to be served quickly. A proficient resource allocation algorithm was proposed by Lee, Jeong and Jang (2014) to allocate VMs to the proper host nodes so that a large number of requests for resources could be served in a shorter time. Azaiez, Chainbi and Chihi (2014) used a genetic algorithm (GA) based scheduling algorithm to allocate cloud resources in order to reduce carbon dioxide emissions and minimize energy consumption.

A generic security-sensitive scheduling model was developed by Kolodziej *et al*. (2014) for computational grids to reduce the power consumption in cyber-physical systems. In the proposed scheduling model, they introduced two more criteria for scheduling, viz., security and energy consumption. The models they presented are not just restricted to the grid system but can be extended to the cloud environment as well.

Xu *et al.* (2014) proposed a green cloud task scheduling (GCTS) algorithm based on the binary particle swarm optimization (PSO). The matrix computation of binary PSO was replaced by a pipeline number. Particle position and velocity were redefined to successfully evade the matrix operations and improve resource consumption. In another work, simulation annealing was used for scheduling the tasks to achieve maximum workload balance and resource utilization and a reduction in power consumption in a cloud computing environment (Xu, Cao, & Wang, 2016). Ferreira *et al*. (2015) proposed an algorithm called Power Load Distribution Algorithm in Depth search (PLDA-D) that is capable of reducing the power consumption of electrical infrastructure. The case studies confirmed that the operational energy

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improved by 17.8% and the power consumption improved by 2.95%. Kaur and Midha (2016) focused on preemptive scheduling to estimate the energy consumed by the computing servers in scheduling the jobs. They proposed an energy-efficient scheduling algorithm that implements a priority-based preemptive job scheduling algorithm for cloud computing with the aim of reducing the power cost.

The stochastic optimization problem was formulated by Zhang *et al*. (2016) to address the issues related to energy sustainability and channel allocation. The problem was solved using a net gain optimal algorithm that was capable of making a control decision without prior knowledge of the stochastic processes. Reduction in energy consumption and SLA violations can be achieved using VM migration and consolidation. Two VM placement heuristics have been proposed by Huang, Wu and Moh (2014), which were scalable and efficiently reduced the number of VM migrations, SLA violations, and lowered the energy consumption. They had improved upon an existing Least Increase Power (LIP) algorithm with Host Sort Algorithm (HSA) and proposed Best Fit Host (BFH) algorithm to find the most suitable host for each VM and Best Fit VM (BFV) algorithm to find the best set of migrated VMs from the list of migrated VMs. A dynamic VM consolidation approach was proposed by Farahnakian *et al*. (2015) to remove needless VM migration and reduce SLA violations using the utilization prediction model. Lin, Liu and Guo (2015) proposed a VM placement algorithm that takes into account multi-dimensional resource allocation such as CPU, memory, network bandwidth, etc. This system not only met the operational costs but also met the QoS requirements of the cloud environment.

Koutsandria *et al*. (2016) proposed a technique to reduce the energy usage and the delay related to profit. Their proposed migration system was implemented using an improved version of the Energy Conscious Task Consolidation (ECTC) algorithm. They had taken into account both the QoS needs of the customer and the profit of the service provider. The system performed efficiently with a smaller load. To address the issue of energy consumption in the data centers, Long and Ji (2016) designed a power-efficient immune clonal optimization algorithm for task scheduling. The clonal selection algorithm, which is a special class of immune algorithm, was proposed by Shu, Wang and Wang (2014) to improve the cost-efficiency and power consumption in large-scale clouds. Liu proposed a model to reduce energy consumption by cloud computing. This model made use of the clonal immune algorithm and suggested a green cloning scheduling optimization. This algorithm efficiently reduced the execution time, energy consumption, and resource utilization as well as improved the scheduling efficiency (Liu, Shu & Zhang, 2016).

B. Architecture-Based Approach

Kliazovich, Bouvry and Khan (2012) presented a simulation environment for cloud computing-based data centers. This simulator not only addressed the workload delivery problem of the data centers but also captured the details of energy consumption by the various devices in the data centers and the communication pattern at the packet level in a real-life setup. The CyberGuarder, a virtualization security assurance architecture, was proposed by Li *et al*. (2012) to address numerous security-related issues of green cloud computing. It provides a security service for VM and virtual networks, along with a policy-based trust management service.

QoS in cloud computing is provided by the Metascheduler Architecture (MACC). It is possible to extend this solution to the green IT platform. A variation of GreenMACC was proposed and evaluated by de Carvalho Junior *et al.* (2016). In their pioneering work, Fioccola *et al*. (2016) proposed a new energy-aware resource arrangement framework for distributed cloud infrastructures. The aim of their work was to show how both network and IT resources could be managed in a typical optical backbone while keeping the overall power consumption and carbon footprint to a minimum. The proposed system architecture consisted of three layers—physical, virtual, and management layers.

Integrated Green Cloud Architecture (IGCA) that consisted of client-centric Green Cloud Middleware for the reduction in energy consumption for both private and public clouds was proposed by Hulkury

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and Doomun (2012). This middleware took into account some of the features of the real cloud scenario, such as heterogeneity of hardware, the capacity of the server, and networking. Based on the concept of hybrid optical switching (HOS), Fiorani *et al.* (2014) proposed an integrated intra-data-center and core network architecture. The core network offers connectivity between data centers, and between data centers and IP networks. An intra-data-center is responsible for providing connectivity among the servers in a data center. Compared to the non-integrated HOS solution, the proposed architecture provided better energy efficiency.

To reduce the cost associated with energy, it has become essential to guarantee energy efficiency at all layers of the cloud. A system architecture was proposed by Alzamil *et al.* (2015) to profile and evaluate the energy efficacy of cloud infrastructure resources. They implemented the architecture in an existing cloud to support energy-aware profiling. An energy modeller has been presented that permits energy awareness at the VM level.

To facilitate the autonomic service routing protocol to create an energy-efficient path in a collective cloud architecture, Itani *et al*. (2015) designed and implemented a novel green-route which independently selected the optimum set of composite service mechanisms capable of supporting the most effectual energy consumption characteristics among a set of providers for executing a specific service request. The outcome was an improvement in energy savings in the general cloud architecture. Saponara, Coppola and Fanucci (2012) proposed an architecture for IaaS that was based on ARM with the inclusion of a new A64 64-b extended instruction set. It enables the use of Advanced RISC Machines (ARM) cores in the server. This guarantees huge savings in energy because ARM chips ensure speed as well as reduced power consumption, leading to reduced cooling.

Tyurin and Kamenskih (2017) proposed a synthesis technique for fault-tolerant delay-insensitive circuits. The implementation of this method would help the developers of green hardware to minimize energy consumption and increase the performance and reliability aspect of QoS.

C. Framework Based Approach

A carbon-aware green cloud architecture was proposed with the aim of reducing the carbon footprint but without affecting the QoS performance of the system. The result was evaluated with respect to the IaaS cloud. A framework for the auto management of the resources of cloud computing was proposed by (Guazzone, Anglano and Canonico (2011) to reduce energy usage at the system level. Their goal was achieved using VM migration, which had shown a noteworthy improvement in energy consumption when compared to frameworks that did not allow VM migration.

Instead of VM, a virtual data center can also reduce energy consumption and the emission of greenhouse gases. A dynamic migration algorithm using Software Defined Networking (SDN) was proposed by Anan and Nasser (2015) with respect to the SLA. This method placed the VMs dynamically in a green computing cluster. The outcome is the higher utilization of servers in the data centers. Idle servers could be turned off, leading to power savings.

Traditional green computing solutions focus on reducing the performance of the cloud data center hosts. Chang *et al*. (2015) proposed a novel framework to improve energy efficiency using VM allocation to minimize power consumption in a data center. The proposed technique shortened the switching time of the server from the low power state to a working state. This method not only made the data centers energy efficient but also reduced their operational costs.

The size of the data is another contributing factor in the energy consumption of a data center in a cloud computing scenario. An adaptation framework, driven by the extraction of data value from the dataset of a given application, was proposed by Ho and Pernici (2015). This framework treated the data according to its significance. An optimization framework for the management of green data centers was

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proposed by Pahlevan *et al.* (2017) A multilevel energy reduction technique was used to obtain an approximate 96% cost savings in electricity consumption.

D. Models and Methods Based Approach

The sustainability of the data centers and clouds was evaluated by Bash *et al.* by building economic, ecological, and social models and then projecting them on various resources such as IT equipment, cost of power supply, source of power, etc. A prototype of this model was implemented on the Open Cirrus Cloud testbed. Cloud computing works with heterogeneous devices across various data centers. To exploit this property of the cloud Garg *et al*. (2011) proposed a near-optimal scheduling strategy taking into account different energy efficiency aspects such as workload, CPU power efficiency, rate of carbon dioxide emission, energy cost, etc. Many of these aspects are dependent on location, architecture, and the management of the data center. The proposed design was able to achieve about 25% energy savings when compared to other profit-based scheduling strategies.

VM migration to deliver distributed services to various data centers in a cloud architecture maximizes the utility of resources and minimizes the computational cost. However, it causes huge energy consumption and carbon dioxide emissions. An integer programming-based migration model was proposed that can be used to find the trade-off between energy consumption and the carbon footprint. Nonde, Elgorashi and Elmirgahni (2016) developed a Green Virtual Networking Embedding (GVNE) using mixed energy linear programming (MELP) to optimize non-renewable power consumption and carbon footprint. The model was found to reduce carbon dioxide emissions by 32%.

Auto-scaling is a technique in cloud computing to dynamically allot resources to applications depending upon their current load. This eliminates idle resources and prevents the wastage of energy. A model-driven auto-scaling infrastructure was proposed by Dougherty, White and Schmidt (2012) for configuration, energy usage, and operational cost. This model could be transformed into a constraint satisfaction problem (CSP) for configuration and minimization of energy consumption. The electricity consumption of the data centers can be controlled by the efficient utilization and scheduling of resources. Chaudhry, Ling and Manzoor (2012) proposed a thermal-aware scheduling and monitoring method to maintain a green yet cost-effective cloud computing system. Hussein, Alkabani and Mohamed (2014) used a fuzzy logic-based approach to address the power management-related problems of data centers. They took into consideration the historical workload data of the VMs and used that to propose a fuzzy rule-based scheduling system to allocate the VMs to different hosts in data centers. Simulation with 50 hosts and 100 VMs achieved a 30% - 40% decrease in power consumption compared to non-fuzzy-based algorithms. However, due to the increase in VM migration, the SLA increased by 32% - 35% leading to a rise in the execution time of VM reallocation.

A complete data center resource management scheme was proposed by Luo *et al.* to achieve both improved QoS and improved green computing objectives. A single resource allocation algorithm may not be sufficient to handle the data center resources, which are quite large in number. They had suggested a modified shuffled frog leaping algorithm to address the resource allocation problem of the VMs. SLA compliance is ensured by turning off idle or underutilised hosts.Idle or under-utilized resources also consume a considerable amount of energy. Effective task consolidation can free up such resources. A heuristic search strategy can be used to search for a resource that would consume minimal energy both implicitly and explicitly without compromising performance. The task is then assigned to such a resource. An energy-aware trust-and-reputation system (TRS) based VM allocation technique was proposed for cloud data centers to reduce energy usage. Their results showed about a 32% improvement in energy consumption when compared to the non-energy-aware-based systems.

The deployment of an effective energy-saving strategy gives rise to conflict between cloud users and owners. A software-based model can enable cloud users to specify their inclination to apply energy-saving methods to some of their virtual resources. This gives the infrastructure managers the ability to

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apply effective load consolidation and to switch their hardware to very low-power states. Arthi and Hamead (2013) analyzed the performance of some of the energy-saving models in use and proposed a novel energy-aware technique where the main features of consideration are energy efficiency. This design included a trigger engine that could initiate auto migration of VM to guarantee energy efficiency. Cappiello *et al*. (2015) considered energy utilization from the application viewpoint. They proposed a method to manage the assignment of applications to the VMs in such a way that the impact on the environment is minimized. They also proposed a novel technique for predicting future emissions trends and recommending appropriate deployment.

E. General Issues

Case studies involving state-of-the-art data centers found that the server utilizations were very high, leading to the high usage of the cooling systems, which is a source of huge energy consumption. There has been a general unwillingness to sacrifice the QoS and as result, many data centers and cloud service providers refuse to explore experimental products that can reduce power consumption, e.g. network solutions like ElasticTree use algorithms and alternative network topologies to optimize the power utilization, however, many companies insist on continuing with the traditional network switches and topologies.

Data centers and cloud providers should always be held accountable for the environmental damage caused by them. The financial cost of this damage is charged back to the consumers. There is a need for linking the data center services to the consumers in such a way that they realize their role in the environmental damage and also that there is clarity about the reasons for the chargeback. Thakur and Chaurasia (2016) made a comprehensive study of the green cloud architecture with an emphasis on Green Cloud Middleware which is in charge of doing the following tasks:

i. Incoming tasks are scheduled by the scheduler.
ii. The cost calculator calculates the cost of performing a task.
iii. Application profiler searches for a suitable application.
iv. The carbon emission calculator keeps track of carbon emission quality.

There are six vital planes in big data enterprise which are responsible for the highest energy consumption for highest energy consumption in a data center. They surveyed the best strategies for reducing the energy consumption of these planes.

Conclusion

Major power consumption takes place in the data centers leading the cloud service providers to worry about the energy-efficiency issue. A harmonious relationship is sought between the cloud service providers, data centers, and ICT equipment producers. Another aspect of cloud computing is the need to address the issues related to e-waste. Cloud technologies, thus, need to be implemented keeping in mind the minimum negative impact on the environment. Green computing models try to find solutions that would help amalgamate the existing technologies with the new techniques to ensure energy efficiency and a reduction in e-waste and carbon footprints.

In this survey, the authors identified five main approaches: algorithm-based, architecture-based, framework-based, models and methods-based, and approaches based on general issues. It appears from Figure 7 that the algorithm-based approach is the most widely employed strategy for the effective implementation of energy efficiency in the cloud environment.

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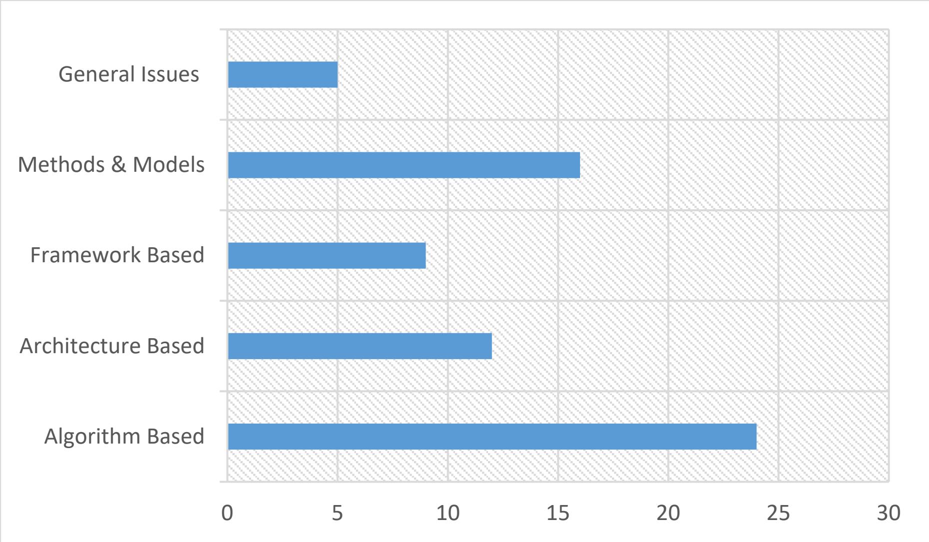

Figure 7: Number of research works consulted for each type of approach

The end-users are found to have the least involvement in the whole energy optimization process. It is thus necessary to create user alertness for the sake of both cost and environmental benefits. In the course of the survey, the authors noted that research needs to be carried out in the following domains:

i. Since the current cloud architecture design consists of multi-core CPUs the energy optimization for such designs is necessary.
ii. Intelligent power consumption system for energy optimization.
iii. Intelligent system technologies for automated VMs creation and resource allocation without hampering the performance of the cloud.
iv. QoS issues, especially the privacy and security aspects, for multi-tenant architecture is another challenge in the area of green cloud computing.
v. Intelligent support for server downtime management, carbon emission calculation, etc. are other key aspects of green cloud computing that are still under-explored.

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Conflict of Interest:

The authors have no conflict of interest.

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