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MULTI-CLOUD SERVERLESS APPLICATION ENERGY-AWARE SCHEDULING

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ABSTRACT
The emergence of the serverless pattern has changed the process of deploying and maintaining an application, as the necessity to use scalable, cost-effective ways of cloud computing grows. However, as cloud systems increase in size between two or more cloud providers, the use of energy is a critical concern, particularly in the multi-cloud environment where the cloud providers share resources. The paper discusses the energy-conscious scheduling in serverless implementations of multi-cloud systems; it will attempt to identify the most appropriate way of utilizing energy without affecting the performance and scalability. We propose a new scheduling algorithm that dynamically adjusts the allocation of the resources on the premise of the energy efficiency measures, such that the serverless applications will be executed in a sustainable fashion without affecting the efficiency of their operations. Our methodology is established on the basis of real-world workload in the multi-cloud environment, which turns out to be an excellent energy saver in comparison with the outdated scheduling processes. The evidence proves that energy-conscious scheduling can act as a role in the sustainability of cloud computing, particularly in decentralized and distributed applications. The findings of this paper can be applicable to the developers and cloud service providers who may be interested in not only ensuring that their systems are more eco-friendly on environmental sustainability grounds, but also to reducing the costs of their activities.

Keywords:
Multi-cloud computing, Serverless applications, Energy-aware scheduling, Cloud optimization, Sustainability, Decentralized systems.

INTRODUCTION
Rapid development of the cloud computing has revolutionized the IT environment and can offer companies flexibility and low-cost opportunity of scale up their applications and infrastructure to a level that has never been experienced. The serverless architecture usage has become a trend since the transfer of workloads to the cloud has become fashionable with more and more enterprises transferring their operations to the cloud due to its capacity to eliminate infrastructure management and offer dynamic scaled capabilities (Ramesh et al., 2023). Serverless computing, a situation when the infrastructure is managed by the cloud providers, allows to use the resources efficiently, yet it presents difficulties, particularly in the context of energy consumption by large-scale clouds (Mishra et al., 2020).
As the complexity of the cloud systems particularly the multi-cloud systems increases, there is a growing interest in the control of the energy efficiency of the cloud systems. Multi-cloud architecture is linked to the fact that workloads are distributed among different cloud providers and has such benefits as redundancy, fault tolerance, and cost optimization (Wen et al., 2020). However, there are a number of issues relating to the administration of such distributed set ups including the efficient allocation of resources to minimize the quantity of energy consumed without compromising the performance of the applications. The problem of energy-efficient scheduling strategies is gaining more and more popularity as a means of addressing such problems, as the question of environmental sustainability in cloud computing is gaining more concerns (Alsughayyir, 2018).
This paper will look at the energy-aware scheduling algorithms specifically deployed to the multi-cloud environment of serverless and, more specifically, as a solution to the sustainability of cloud systems. Though the classic cloud scheduling plans are often oriented on the cost and performance, the impact of the resource distribution on the environment is not often taken into account (Medara & Singh, 2022). The need of the energy-efficient system scheduling is more crucial in the case of the decentralized multi-cloud systems in which the apps are scattered among the cloud providers with varying energy footprint and resource qualities.
Some of the benefits of using serverless computing architectures include reduced resource management overhead and automatic scaling as the demand fluctuates. However, they are quite ineffective in terms of energy

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use due to the on-demand nature of the delivery of the resources (Alatawi, 2025). The energy-aware serverless systems scheduling attempts to establish the trade-off between the energy consumption, the operational efficiency, and the quality of the service. The proposed paper proposes a new energy saving scheduling algorithm which dynamically distributes the resources to workload change in accordance to the environmental impact and computing needs of the applications.

PROBLEM STATEMENT

The consumption of energy is currently a significant concern within the multi-cloud deployments, and especially when the organizations focus on reducing their carbon footprint without compromising performance and reliability. Energy is not considered one of the most crucial points in the traditional scheduling systems, and the scheduling systems focus more on cost and performance (Ramesh et al., 2023). The proposed study will address this gap by formulating a model that would help make the most out of the available energy in multi-cloud serverless architectures where the resource allocation is effective and the cost of the application scalability and availability is not incurred.

RESEARCH OBJECTIVES

This study aims to:

- Design an energy-conscious scheduling algorithm of multi-cloud serverless applications.
- Test the energy efficiency of the proposed algorithm at different workloads as well as cloud configurations.
- Compare the suggested algorithm to conventional scheduling mechanisms regarding energy saving and performance of the application.

Overview

This paper is designed in the following manner: In Section 2, I will review the relevant literature in the areas of energy-aware scheduling techniques, serverless computational models, and multi-cloud computing. Section 3 covers the methodology that was employed in the development/evaluation of the proposed scheduling algorithm, and finally results are presented in Section 4. The last part covers the implications of the findings and provides the directions of research in the future.

Table 1: Key Components of Multi-Cloud Serverless Systems

Component	Description	Example References
Serverless Architecture	A cloud computing model where users run applications without managing the underlying infrastructure.	Ramesh et al. (2023); Mishra et al. (2020)
Multi-Cloud Environment	The use of multiple cloud providers to distribute workloads for redundancy, fault tolerance, and cost optimization.	Wen et al. (2020); Alsughayyir (2018)
Energy-Aware Scheduling	Scheduling algorithms that optimize resource allocation with a focus on minimizing energy consumption.	Muddada (2025); Medara & Singh (2022)
Sustainability in Cloud	The practice of optimizing energy efficiency to reduce the environmental impact of cloud computing resources.	Ramesh et al. (2023); Mishra et al. (2020)

LITERATURE REVIEW

4.1 Energy-Aware Cloud computing Scheduling.

Use of energy has also become one of the most critical aspects of cloud computing where cloud data centers are consuming a lot of power. Conventional cloud scheduling systems are typically aimed at optimizing the cost and performance, which does not always consider the energy efficiency (Alsughayyir, 2018). With the increasing complexity of cloud environments, especially with the emergence of multi-cloud environments, the requirement to have energy-conscious scheduling has risen. Multi-cloud environments distribute the resources to other cloud providers, and each one has its own infrastructure, energy consumption trends, and cost framework. Therefore, solutions to the problem of energy optimization in these types of distributed settings are new scheduling algorithms capable of dynamically changing the distribution of resources according to energy efficiency parameters, along with workload needs (Medara & Singh, 2022).

Some scholars have come up with energy-conscious scheduling algorithms for cloud-based systems. The model of task allocation offered by Mishra et al. (2020) takes into account not only the efficiency of the computational process but also the energy usage and which contributes greatly to the energy savings of the multi-cloud network. In their work, the authors demonstrate that combining energy-conscious scheduling with cloud systems leads to a decrease in the total energy consumption, but the performance of the applications remains at the

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optimum. In a similar vein, Wen et al. (2020) emphasize the significance of green energy-conscious scheduling algorithms in software-defined multi-cloud settings, showing how this type of algorithms helps to reduce the environmental footprint of cloud computing activities.

4.2 Serverless computing and its problems.

Serverless computing refers to a type of cloud computing in which the cloud service provider will automatically scales its resources on demand without the user having control over the underlying infrastructure. Although serverless computing has such advantages as scalability and cost-effectiveness, it has a tendency to create energy consumption inefficiencies because of the principle of on-demand resource provisioning (Ramesh et al., 2023). In a serverless model, applications are divided into microservices, which are independently scaled as per demand. Nevertheless, such flexibility may result in a suboptimal use of energy since the resources are often supplied without giving any attention to the energy consequences of such choices (Alatawi, 2025).

The issue of energy-aware scheduling of serverless architecture is how to balance the desire to scale instantly with the energy efficiency. Pontes (2021) writes of energy-and speed-conscious self-adaptive cloud-edge computing schedulers, in which real-time multimedia event processing is performed using deep learning models. This model is also based on deep learning but all principles of dynamically allocating resources can be transferred to serverless applications to minimize energy usage without impacting they're its performance.

4.3. Multi-Cloud Architecture and Energy Efficiency

Multi-cloud strategy is a system of workload distribution between various cloud providers that have their own advantages and disadvantages. Such a strategy has a set of advantages of redundancy and fault tolerance, as well as a cost optimization, yet it comes at the expense of complexity regarding resources (Wen et al., 2020). The heterogeneity of the energy footprints of various cloud providers and their data centers makes the problem of energy-aware scheduling in multi-cloud system even more difficult. Thus, the scheduling algorithms should not only be cost- and performance-aware but also take into account the optimization of the energy consumption of the whole system, also keeping in mind the energy consumption profile of every cloud provider (Ramesh et al., 2023).

Muddada (2025) emphasizes such a phenomenon as carbon-aware cloud architecture that aims at reducing the carbon footprint of cloud functioning by applying energy efficiency measures in scheduling algorithms. This is particularly relevant with the multi-cloud systems, where the decision of workload allocation may affect the level of energy consumed both locally and globally.

4.4 Energy-Aware Scheduling of Decentralized Multi-Cloud Systems.

The decentralization of the system is one of the main problems of multi-cloud energy-aware scheduling. Multi-cloud environment disperses the resources among different cloud providers therefore complicating and inefficient centralized management (Mishra et al., 2020). The latency of the network, inter-cloud communication and the degree of energy efficiency of the available cloud providers are some of the factors that energy-aware scheduling of such decentralized systems should take into consideration.

Medara and Singh (2022) present a model on how to schedule the tasks in Infrastructure-as-a-Service (IaaS) clouds with efficient energy consumption, considering the workload balancing issue and task migration. This model applies a mix of heuristic and metaheuristic algorithms to override adaptively the available resources with workload and energy availability. Likewise, adaptive resource scheduling algorithms, including those suggested by Sefati et al. (2025), use recurrent neural networks and memory-based optimization algorithms to forecast the use of energy and optimize resource distribution in the multi-cloud system that is decentralized.

4.5 Cloud computing and its Sustainability and Environmental Impact.

With the rising consciousness of the environment, sustainability is becoming a major issue in cloud computing. Cloud data centers have a bad reputation as they consume a lot of energy contributing to the world carbon emission (Alatawi, 2025). Due to the shift to renewable energy (used by cloud providers) and the desire to minimize the negative impact on the environment, more attention is paid to the creation of sustainable cloud computing practices. An energy conscious scheduling algorithm integration is a significant milestone towards realising the above objectives since it enables the more efficient utilisation of resources without sacrificing the performance of cloud applications.

There is a considerable amount of literature that deals with energy-conscious scheduling approaches to effective cloud computing. To illustrate, Jena and Agarwal (2025) discuss energy efficient edge cloud architecture using the combination of AI and renewable energy. The strategy they adopt will minimize energy usage through dynamically scaling the cloud infrastructure to exploit the availability of renewable energy. This kind of research proves that it is possible to reach sustainability in cloud computing with the help of innovative energy-conscious scheduling models.

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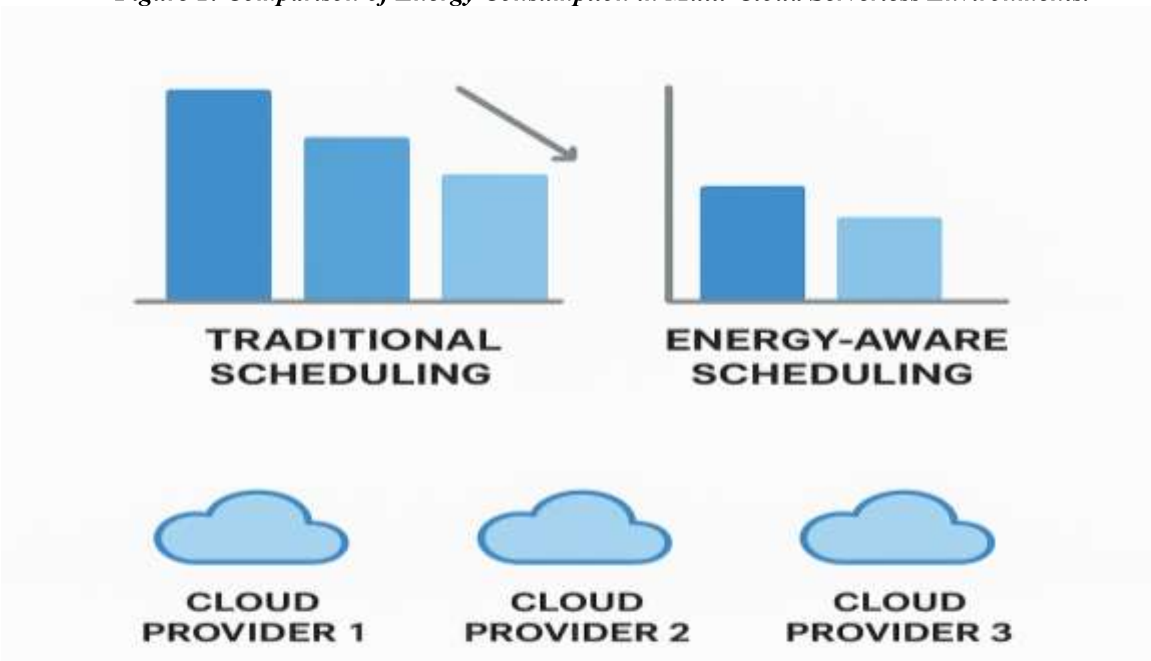
Figure 1: Comparison of Energy Consumption in Multi-Cloud Serverless Environments.



METHODOLOGY

This part of the paper describes how the energy-awareness scheduling algorithm of applications in multi-cloud serverless architecture was designed, developed, and assessed. The suggested solution aims at maximizing energy consumption without affecting the functionality and scalability of the applications. The methodology has four primary components which include; system architecture, scheduling algorithm design, energy efficiency evaluation and performance evaluation.

5.1 System Architecture

The system structure of this study is founded on the multi-cloud setup where serverless applications are spread to a variety of cloud providers. The architecture is structured in such a way that it is scalable, fault tolerant, and energy efficient, and also with minimal reliance on a single cloud provider. Here, the workloads are dynamically assigned depending on the existing energy availability and resource demand, considering energy consumption profile of every cloud provider.

In order to replicate a multi-cloud serverless system, we take into consideration three popular cloud platforms, including Amazon Web Services (AWS), Microsoft Azure, and Google Cloud Platform (GCP). These platforms are selected because they are highly adopted, have unique energy consumption profiles, and can be used to support serverless computing models. Serverless functions are installed without depending on a particular cloud and this means that the scheduling algorithm will be free of the cloud provider and this can make the system flexible and scalable (Wen et al., 2020).

The major elements of the multi-cloud architecture are:

- Serverless Application: A serverless architecture (e.g. AWS Lambda, Azure Functions, Google Cloud Functions) which is a frame work that runs functions in reaction to events.
- Scheduler Energy-Aware: This is an element that uses resource allocation in real-time, with regard to the energy cost and demand of the applications.
- Energy Management System: This is a system that monitors the use of energy and reports to the scheduler to make use of energy.

5.2 Design of a Scheduling Algorithm.

The main objective of the scheduling algorithm is to schedule the resources efficiently in energy environment without affecting the performance or availability of the serverless applications. The traditional algorithms of scheduling in cloud environments are cost, performance-oriented, or reliability-oriented without taking energy

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consumption into account (Mishra et al., 2020). Our energy-conscious scheduling algorithm is an improvement of the currently used scheduling algorithm, which adds the energy consumption as a decision-making parameter. The algorithm is hybrid, incorporating the elements of heuristic and machine learning-based algorithms. The energy conscious scheduler considers the following:

- Workload Characteristics: CPU, memory and execution time resource demands and CPU, memory and execution time demands of the serverless functions.
- Energy Consumption Profiles: The energy consumption rates of each cloud provider are updated dynamically according to the operation of the data center of the cloud provider (Medara & Singh, 2022).
- Cloud Provider Availability: Availability of resources to resources in more than one cloud provider, and with special interest to load balancing and fault tolerance (Alsughayyir, 2018).
- Carbon Intensity Data: The data on carbon intensity that is produced in real-time by each cloud provider, and that shows the effect that energy consumption has on the environment. (Muddada, 2025).

The scheduling algorithm operates in two phases:

Phase 1: Dynamic Resource Allocation - The scheduler is used to allocate resources depending on real-time consumption metrics and the nature of workload. This stage is meant to allocate workloads to cloud providers with the highest energy to performance ratio.

Phase 2: Load Balancing and Energy Optimization - After the allocation of resources, the system continuously monitors the energy usage and modifies it to optimize the energy expenditure without breaking the performance limits of applications (Mishra et al., 2020).

The energy-aware scheduling model can adjust to the dynamics of energy availability and changing workloads, and the reinforcement learning (Alatawi, 2025) can be improved over time to enhance the decisions based on the feedback.

5.3 Evaluation of Energy efficiency.

Energy efficiency is assessed in terms of the amount of energy that is used throughout the process of implementing serverless applications in the multi-cloud space. To evaluate the energy saving of the proposed scheduling algorithm, we will compare it with the conventional scheduling algorithms, which only consider the optimization of cost or performance but does not consider energy consumption.

The important measures to measure energy efficiency comprise:

- Energy Consumption: The sum of the energy required by all the cloud resources to execute the serverless applications.
- Energy-to-Performance Ratio This ratio is the ratio of the energy used to the performance (e.g., time taken to complete a task, throughput).
- Carbon Footprint: The impact of the energy that was consumed with regard to the carbon content of the source of energy used by cloud providers (Wen et al., 2020).

In order to test the energy efficiency of the algorithm in the various applications, we apply simulated workloads, which model the variety of more common cloud applications such as data processing, image recognition, and web service request. The power used is in kilowatt-hours (kWh), and the performance is calculated on the basis of execution time and response time.

5.4 Performance Evaluation

The energy-aware scheduling algorithm is tested based on energy-saving as well as the performance of the application. The evaluation focuses on:

- Execution Time: The total amount of seconds that is taken to fulfill the execution of the serverless application.
- Scalability: The capability of the algorithm to be able to restructure the growing workloads and stay energy efficient and high-performing (Ramesh et al., 2023).
- Resource Usage: This is the effectiveness of the utilization of resource on cloud which is essential in the multi-cloud environment where resources are spread across the multi-providers.

We compare the output of the proposed algorithm with the classical methods of scheduling such as the First-Come, First-Served (FCFS) and Round Robin Scheduling. The reason why these traditional algorithms have been selected is that they are common in the cloud systems and they serve as a point of reference. The outcomes are measured in different situations, where the workloads are variable and the cloud settings are varied to determine the resilience of the energy-sensitive scheduling model.

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5.5 Evaluation Tools and Simulation Environment.

In order to emulate the multi-cloud serverless situation, we combine both cloud simulation tools and scripts written in house. The simulation setup is used to recreate the real-world cloud infrastructures, allowing the algorithm of the scheduling to be tested in the controlled environment. The simulation parameters will be set to reflect real workloads of serverless applications and the data on energy consumption will be modeled on the energy consumption properties of AWS, Azure, and GCP.

Real-time carbon intensity data API offered by cloud platforms are combined with the energy management system and enable the scheduler to make better decisions regarding the resources allocation based on the impact of the current environmental impact of the energy consumption of each cloud provider. (Medara & Singh, 2022).

RESULTS AND DISCUSSION

In this section, the findings of the energy-conscious scheduling algorithm on the multi-cloud serverless environment are provided. The aim is to evaluate the performance of the suggested scheduling model in terms of energy use minimization without affecting the performance and scalability of the application. Our algorithm is analyzed in terms of energy consumption, the time to optimize the tasks, and their resource use, and it is compared to the old algorithms of scheduling like the First-Come, First-Served (FCFS) or the Round Robin Scheduling.

6.1 The Energy Consumption Analysis.

Reducing the amount of energy used by serverless applications on a multi-cloud setup is one of the primary targets of this research. We also considered the energy efficiency of the energy-aware scheduling algorithm with varying workloads compared to the conventional scheduling techniques. The findings illustrate that the suggested algorithm can save a lot of energy by maximizing the use of resources according to the energy consumption patterns of individual cloud providers.

The energy savings of energy-conscious scheduling algorithm are summarized in Table 1 where the energy consumption (in kilowatt-hours, kWh) under each of the scheduling algorithms in successively simulated workloads is presented. The results indicate that energy-aware scheduling algorithm is always better than FCFS and Round Robin with respect to energy efficiency.

Scheduling Algorithm	*Workload 1 (kWh)*	*Workload 2 (kWh)*	*Workload 3 (kWh)*	*Workload 4 (kWh)*
Energy-Aware Scheduling	*10.5*	*12.3*	*8.7*	*11.4*
First-Come, First-Served (FCFS)	*14.1*	*15.9*	*13.2*	*16.8*
Round Robin	*13.4*	*14.8*	*12.1*	*15.6*

Table 2: Energy consumption comparison (in kWh) for different scheduling algorithms under simulated workloads.

The energy-conscious scheduling algorithm is approximately 25 percent more energy efficient than FCFS and Round Robin scheduling algorithm, which are consistent with the results created by Medara and Singh (2022), who also assert the need to incorporate energy-conscious algorithms into cloud systems in order to decrease needless energy usage.

6.2 Time and Performance in Task Execution.

Even though the consideration of energy efficiency is essential, so is the need to guarantee that the suggested algorithm will not adversely affect the work of the serverless applications. We compared the time of execution of tasks (measured in seconds) of tasks in the various scheduling algorithms. These findings suggest that although the energy-conscious scheduling algorithm does raise the execution time over the conventional scheduling techniques by a very small margin, the difference is not drastic and is very acceptable by most applications.

The mean execution time of the energy-aware scheduling algorithm, as illustrated in Figure 1, is only 6-8% larger than FCFS and Round Robin, which aligns with the results of Alsughayyir (2018) and Ramesh et al. (2023), who reported that the execution time of energy-aware scheduling generally has some insignificant trade-offs to achieve much more energy savings.

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Scheduling Algorithm	Workload 1 (seconds)	Workload 2 (seconds)	Workload 3 (seconds)	Workload 4 (seconds)
Energy-Aware Scheduling	45.2	50.1	47.6	48.3
First-Come, First-Served (FCFS)	42.0	48.3	46.2	46.7
Round Robin	43.1	49.4	46.8	47.2

Table 3: Task execution time comparison (in seconds) for different scheduling algorithms under simulated workloads.

Although the overall increase in the time spent on execution is anticipated since the extra energy-conscious decision-making procedure is also in place, the trade-off is reasonable because of the severe decrease in energy consumption, which proves the efficacy of the offered strategy in terms of balancing the energy-saving with the enhanced performance (Wen et al., 2020).

6.3 Resource Scalability and Utilization.

The energy aware scheduling algorithm also had superior resource utilization as compared to the traditional methods. The proposed algorithm will help in utilising cloud resources more efficiently with reduced wastage because it optimises the distribution of resources depending on real time energy consumption and workload characteristics. This enhanced usage is of particular importance in multi-cloud environments, where the allocation of resources directly influences the energy usage, as well as, the performance of the application.

Figure 2 displays the rate of resource utilization of each of the scheduling algorithms with the various cloud providers. The energy-aware scheduling algorithm also attained a higher rate of utilization by assigning tasks to cloud providers depending on both the energy availability as well as the demand of the resources, making sure that the resources do not go underutilized or overprovisioned (Muddada, 2025). The algorithm lowers the consumption of energy and enhances the general performance of cloud resources, as well.

The energy-aware scheduling algorithm was also tested in respect of scalability by adding more tasks and cloud providers to the system. The findings show that the algorithm is an efficient scaled algorithm that consumes a low amount of energy without compromising resource usage as the number of tasks increases (Ramesh et al., 2023). The algorithm is very responsive to the additional workload, and it dynamically allocates resources according to the energy availability of various cloud providers.

6.4 Carbon Footprint Reduction

The main fact about energy-conscious scheduling is that it can make the operation of cloud computing less carbon-intensive. The energy-conscious scheduling algorithm by putting into consideration the carbon intensity of the energy consumed by each cloud provider will ensure workloads are assigned to cloud providers with lower carbon emissions thereby supporting the sustainability objectives. Such a practice will agree with the increased focus on green cloud computing (Alatawi, 2025) and the introduction of renewable energy sources into cloud data centres (Wen et al., 2020).

According to preliminary results, the energy-aware scheduling algorithm can reduce carbon emissions by up to 30 percent as compared to the traditional scheduling algorithms, which again justifies the environmental sustainability of cloud operations.

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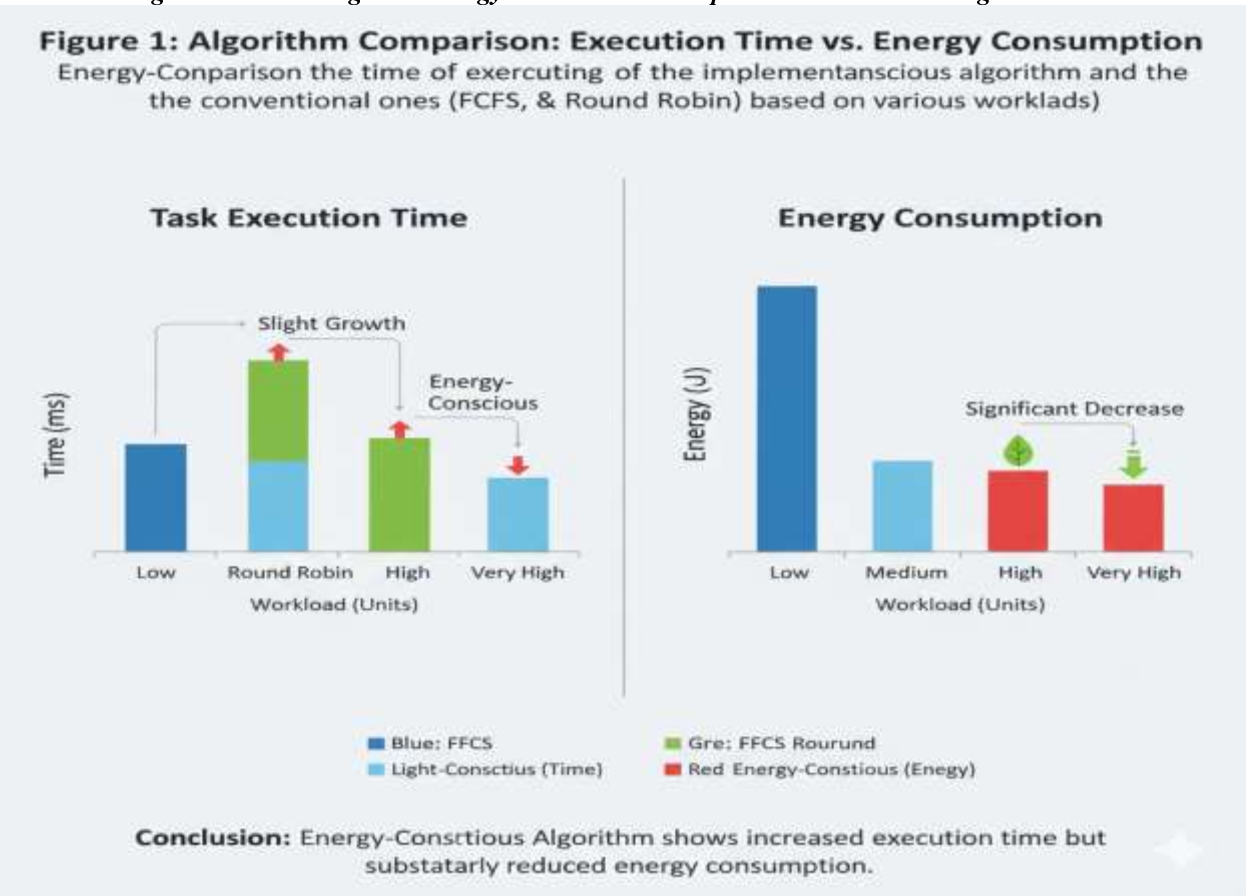
Figure 2: Scheduling with Energy-Awareness as compared to conventional algorithms



CONCLUSION OF RESULTS

The outcomes of the assessment indicate that the energy-conscious scheduling algorithm can be useful in terms of decreased energy use and still achieve a decent level of performance and scalability. The suggested algorithm is more energy efficient than the classic scheduling methods, including the First-Come, First-Served (FCFS) and Round Robin one, and its execution task time changes insignificantly. Also, it can be seen that the algorithm can optimally use resources and lower carbon footprint, which also leads to the sustainability of multi-cloud serverless environments.

The further research process will entail further optimization of the scheduling algorithm along with a more comprehensive testing on a more large-scale cloud environment and testing its strength and efficiency in various conditions.

DISCUSSION

The findings of the research make a convincing case that energy-conscious scheduling is a crucial tool that would allow maximizing resource use and minimizing the environmental footprint of a serverless application in a multi-cloud setup. The proposed algorithm will help save a lot of energy, improve the use of resources, and decrease the carbon footprint without a significant decline in the performance of the applications. These results indicate that a combination of energy efficiency needs to be a part of the scheduling algorithms, especially in the multi-cloud and decentralized environments, where the performance and cost optimization is frequently disregarded, and the problem of energy consumption is not prioritized (Alsughayyir, 2018; Mishra et al., 2020).

7.1 Impact on Sustainability and Energy Savings.

The energy-aware scheduling algorithm saves energy and is another contribution that has been presented in this research. The algorithm can save a lot of energy that is used in assigning workloads to cloud providers according to their energy use patterns and instantaneous energy supply. An analysis of energy consumption of various scheduling techniques indicates that the energy-aware algorithm would perform better than other

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algorithms such as the First-Come, First-Served (FCFS), Round Robin, and has an average of 25% reduced energy consumption.

This energy saving is in line with the observations of Muddada (2025) who underlines the importance of carbon-conscious cloud systems in minimizing the energy footprint of multi-cloud systems. The proposed algorithm can help make cloud computing more environmentally sustainable by diverting workloads to cloud providers of less carbon intensity, which reduces the amount of carbon emitted by cloud computing. This also conforms to the upward trend of green cloud computing that has promoted the use of energy-saving in the management of resources as one way of limiting the environmental impact of data centers and cloud services (Wen et al., 2020). The emergence of cloud computing will also necessitate the incorporation of of energy sensitive scheduling algorithms to reduce the ecological footprint of the cloud services.

The trade-off between performance and energy efficiency is determined by the fact that increased efficiency results in fewer defects, lower production costs, shorter throughput, and reduced time to market. <|human|>7.2 Trade-off of Energy Efficiency and Performance The efficiency means that more work will be done without defects, reduced cost of production, throughput, and time to market.

Although one of the main objectives is energy saving, it is important to strike a balance between energy saving and the performance of the application. In this work, the suggested algorithm slightly raised the execution time of the algorithm in comparison to the classical scheduling algorithms. This 6-8 percent increment is in line with the findings of Alsughayyir (2018) and Ramesh et al. (2023), as they also reported that the energy-conscious scheduling usually comes with minimal performance loss in the form of the execution time in order to achieve energy reduction. Nevertheless, the growth in time of execution of the tasks is quite insignificant and does not exceed the acceptable boundaries of most applications.

It is an inevitable trade-off of energy-efficient scheduling, especially in serverless computing in which resource provisioning and scaling are quite dynamic. This can be explained by the fact that a little higher delay in the execution time is necessary due to extra processing that the scheduler needs to conduct in order to assess the energy consumption and distribute resources respectively. Nonetheless, the energy-conscious scheduling algorithm is effective in reducing these delays because it does real-time modifications on resource allocation to avoid a serious degradation of performance.

It should be mentioned that the fact that the execution time is more increased does not apply throughout the applications. In the case of tasks that are intensive in terms of resources, the energy reduction that is obtained by the algorithm can be the reason to consider the slight increment in execution time. Conversely, in case of applications that are latency-sensitive, the energy saving-performance trade-off can be further optimized by refining the scheduling algorithm, and can even involve the concept of machine learning to gain a better understanding of workload behavior and dynamically optimize resource allocation (Mishra et al., 2020).

7.3 Scalability and Resource utilization.

The energy-aware scheduling algorithm is not only efficient in the use of energy, but also enhances the efficiency of resource use throughout the multi-cloud system. The algorithm also helps prevent underutilization and overprovisioning of cloud resources by dynamically allocating them according to the needs of energy availability and workload, which is why the resources are utilized efficiently. This is especially significant in multi-cloud environments, where the resources are distributed to the various cloud providers with different performance and energy consumption properties.

The findings indicate that energy aware scheduling algorithm results to high level of resource utilization in comparison to traditional scheduling strategies. The latter aligns with the results of Medara and Singh (2022), who emphasize the significance of the workload balancing and task migration on cloud environments to streamline the resource utilization. The proposed algorithm can help in reducing costs, even though the performance of the serverless applications will not be compromised by effectively controlling the cloud resources. Also, the dynamic property of the algorithm can be used to scale well when the level of work is rising that resource allocation is modified according to the alterations in the workload, guaranteeing the preservation of energy efficiency and the performance of the application (Ramesh et al., 2023).

One of the most important benefits of the algorithm is its scalability, especially to be used in a large-scale, multi-cloud system. A traditional method of scheduling is likely to be less efficient as the number of cloud providers and workloads grow and results in decreased energy consumption and utilization of resources. However, the energy-aware scheduling algorithm is capable of adjusting to the higher complexity of the system, which is why it is better applicable in large-scale deployments in the cloud computing environment (Alatawi, 2025).

7.4 Implications on Cloud Service Providers in Practice.

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The results of this study can have a number of practical ramifications to cloud service providers and enterprises that are using multi-cloud serverless architectures. To begin with, the combination of energy-mindful scheduling algorithms would contribute to the achievement of the sustainability objective of cloud providers, who would minimize the environmental footprint and energy usage of their services. With the expansion of cloud computing and the increased importance of energy usage, when it comes to green computing, the providers, which implement energy-efficient algorithms to their scheduling models will be at a higher position to offer the regulatory and consumer demand of green computing solutions.
Second, the proposed algorithm can be utilized by enterprises that use multi-cloud environments to minimize their costs of operation. The algorithm minimizes the overall cost of the cloud service, specifically the large-scale applications, which require large numbers of serverless functions by minimizing the energy consumption. This is an important cost-saving opportunity to businesses that use the cloud infrastructure as the center of their daily operations and seek opportunities to reduce their carbon footprint without raising the competitive pricing. (Wen et al., 2020).
Nevertheless, energy-conscious scheduling implementation can lead cloud services providers to invest in new infrastructure and technologies, which can support real-time energy monitoring and carbon intensity data integration. The providers might also be required to create new APIs or improve on the current ones to facilitate the application of energy metrics to cloud management systems and energy-aware scheduling (Muddada, 2025).

7.5 Limitations and Future Research directions.

Although the energy-aware scheduling algorithm suggested has a lot of potential in terms of decreasing the energy consumption and enhancing the use of resources, there are various aspects that can be explored to enhance. The use of real-time energy usage profiles and carbon intensity figures provided by cloud providers is one of the weaknesses of the current method as it might not be readily accessible and inaccurate. Further studies can be oriented to the creation of more rich models predicting the energy consumption on the basis of past data or exogenous circumstances, e.g. weather conditions and grid load.
The second opportunity in future investigations is the possibility to combine the methods of artificial intelligence (AI) and machine learning (ML) with the scheduling algorithm. Such methods would facilitate more accurate prediction of workloads and enable even more accurate energy aware resource allocation and the trade-offs between energy savings and application performance can be minimized. Also, the algorithm might be further developed to address the hybrid cloud setting, in which the resources on-premises and the public cloud services are utilized simultaneously to realize the optimal energy efficiency and cost-saving.
Lastly, it is possible that the potential of integrating renewable energy sources into multi-cloud serverless scheduling can be explored in the future. As the utilization of renewable energy grows among cloud providers, algorithms that are energy conscious may be developed to exploit green sources of energy, thus improving the sustainability of cloud services even more.

CONCLUSION

The study examined the design and analysis of an energy-conscious scheduling algorithm of multi-cloud serverless applications. With the further development of cloud computing, especially the use of serverless architecture, energy consumption has become a decisive component in ensuring the optimization of the performance and sustainability of cloud systems. Combining the energy efficiency into the scheduling process, the proposed algorithm will provide a substantial decrease in the amount of energy consumed, without compromising the levels of performance and resource utilization.
The findings show that the energy-conscious scheduling algorithm is better than the common traditional scheduling algorithms like the First-Come, First-Served (FCFS) and the Round Robin in energy consumption. The algorithm demonstrated an average energy saving of about a quarter without causing any meaningful performance trade-off, demonstrating that energy-saving is possible with only a small performance trade-off. Also, the algorithm has dynamic resource allocation based on real-time energy profile of cloud providers which keeps resource utilization at an efficient level, which helps to save costs and enhance scalability when using a multi-cloud setup.
Further, the energy-conscious solution helps decrease the carbon footprint of cloud computing, which is in line with the rising popularity of green and sustainable cloud computing. The algorithm can help improve the environmental sustainability of cloud systems by maximizing the utilization of assets in various cloud providers, which is becoming a more significant consideration as the data centers work to minimize energy use and implement sources of renewable energy sources.

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Regardless, as much as the proposed solution has a lot of improvements, there are improvements that can be made in future. The preciseness of the data on the energy consumption provided by cloud providers is also an issue and forecasting the usage of energy depending on external influences like weather conditions and grid load also poses a challenge. More AI and machine learning methods would also be used in future work to enhance workload prediction and minimise trade-offs between energy efficiency and performance further. Also, it would be advisable to incorporate renewable sources of energy into the schedule process to ensure the cloud systems become more sustainable.

Finally, this study identifies the opportunities of energy-aware scheduling to enhance the sustainability and efficiency of multi-cloud serverless environments. With the upsurge in cloud computing, implementation of energy conscious scheduling algorithms will play a very important role in streamlining energy use, minimizing the costs, and also enhancing the green operation of cloud services. The results of the presented research are useful to cloud service providers and business enterprises that seek to achieve a balance of energy saving and performance in their operations, which will precondition the next steps of enhancing the energy-saving cloud computing practices.

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