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Energy Efficiency in Cloud Computing Infrastructure

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ABSTRACT

Introduction: The rapid expansion of cloud computing infrastructure, notably to support artificial intelligence and digital services, has led to a significant increase in energy consumption, raising serious environmental and sustainability concerns.

Objectives: This research aimed to conduct an in-depth review of existing energy-efficient cloud computing approaches and explore potential novel methods for enhancing energy efficiency without compromising system performance.

Methods: A positivist quantitative research philosophy was adopted. Data were collected through an online survey of 31 respondents working in the IT and cloud computing sectors. The collected data were then analyzed using quantitative statistical techniques to assess the effectiveness of current energy-saving strategies.

Results: The analysis identified virtualization, dynamic resource scheduling, and advanced cooling systems as the most effective current techniques for reducing energy consumption in cloud infrastructure. Furthermore, AI-driven automation and serverless computing were highlighted as promising future technologies. However, the study also found that ageing infrastructure and growing demand remain significant challenges to achieving sustainability.

Conclusions: To ensure the scalability and long-term sustainability of cloud computing without negative economic or environmental impacts, integrating AI-based optimization, renewable energy sources, and green computing principles is essential. These strategies can potentially make cloud infrastructure more energy-efficient and environmentally responsible.

Keywords: Energy Efficiency, Cloud Computing, Sustainability, AI-driven Optimization, Green Computing.

INTRODUCTION

The energy consumption of cloud computing infrastructure has become a significant concern as the demand for AI-based applications and digital services is consistently increasing. Artificial intelligence is used for optimized energy consumption (Raval et al., 2021). AI-based technology helps to anticipate and optimise workload, where companies can optimise the energy required at a particular time. This proactive adaptation avoids increasing energy consumption, activates the necessary servers, and turns off idle factors. Advanced cooling technologies, including cooling with liquid, are being implemented to drastically minimize power usage drastically. For instance, companies like Google and Microsoft have invested in liquid cooling, leading to significant power savings in their data centres .

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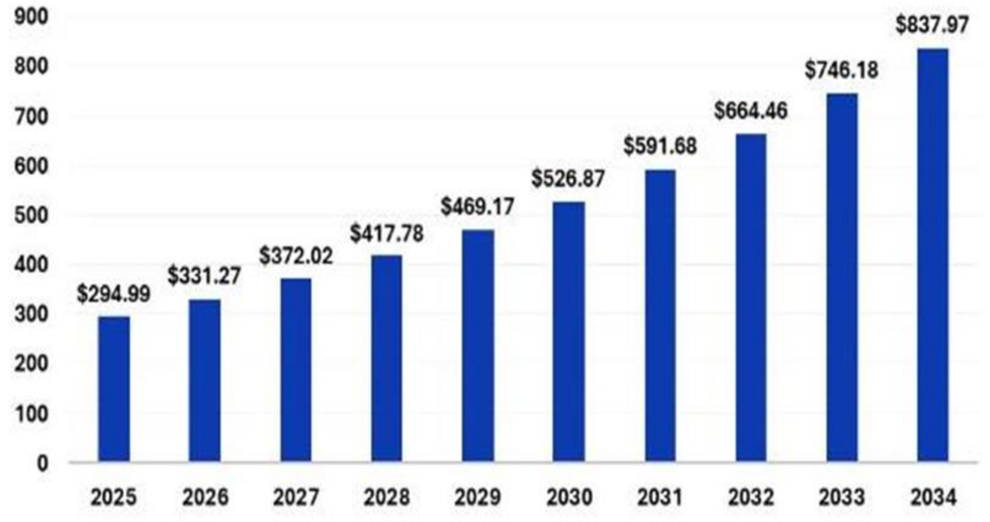

Figure 1: Market Size of Cloud Infrastructure and Forecast

On the other hand, incorporating renewable energy into data centre operations is also rapidly growing. Firms rely on 'on-site renewable resources' such as solar panels and wind turbines to power their facilities, which can significantly reduce carbon emissions.

Moreover, it can be stated that improving the energy efficiency of 'cloud computing' infrastructure is a necessary step for sustainable digital evolution. With innovations in cooling technologies, artificial intelligence for 'energy efficiency' and the increased demand for 'renewable energy', the industry can achieve significant progress in lowering its impact on the environment and minimizing the costs to the planet whilst meeting cloud computing services.

1. Problem Statement

Several complex issues damage the evolution of energy efficiency in the context of cloud computing facilities. One main problem is excessive energy consumption due to exponentially increasing data, AI workloads, and digital services. Many data centres continue to execute operations utilizing obsolete power hardware and outdated systems that are not energy efficient (Katal et al., 2023). The use of antiquated cooling technologies can also preclude cooling for older facilities. Furthermore, the increasing carbon emissions of data centres, as they are consuming fossil fuels, are delaying the impact on the clouds.

On the other hand, the location of data centres also has an integral impact on energy consumption due to climate factors and logistics (Murino et al., 2023). Another problem is the lack of acceptance of sustainable energy sources, especially in areas with poor infrastructure and policy backing. Dynamic workload assignment and virtualization technologies can be beneficial, but this raises inefficiency due to poor management.

OBJECTIVES

Aim: The research aims to examine energy efficiency in cloud computing infrastructure through an in-depth evaluation of present practices and sustainable tactics that can actively reduce energy consumption and ensure optimal performance.

The objectives of the study are:

- To investigate the efficiency of the current energy-efficient mechanisms and strategies (such as virtualisation, dynamic resource scheduling, and cooling systems) applied to the cloud data centres.

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- To assess innovative strategies or models to improve the energy efficiency of cloud computing systems that do not interfere with performance and scalability.
- To analyse the current energy consumption of cloud computing infrastructures from major service providers.

REVIEW RELEVANT LITERATURE

1. The efficiency of the current energy-efficient mechanisms and strategies applied to the cloud data centres

Energy-efficient processes in cloud data centres strive to promote sustainable resource use and reduce environmental impact through energy resource consumption. The principle of server virtualisation, where many virtual servers exist on one physical server at different virtual machine types and run simultaneously with a hypervisor such as VMware, is still the predominant means of enabling an improvement in server utilisation and efforts in reducing energy consumption (Panwar et al. 2022). Virtualisation essentially reduces the number of active physical machines needed to perform computation, which lowers the overall energy consumption of the physical machines used and helps save energy (See Figure 2). Some improvements formulated include dynamic resource scheduling, which utilises changing workloads to allocate computational resources and helps avoid underutilisation and over-provisioning.

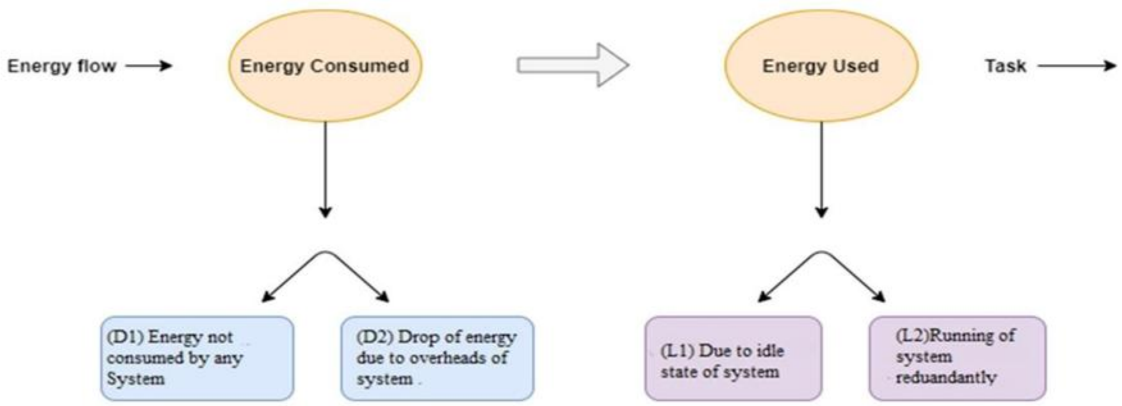

Figure 2: Specific condition by which a system can save energy (Source: Bharany et al. 2022)

Existing research has highlighted updates to a dynamic resource scheduling working with predictive analytics that improved energy efficiency in cloud environments by 30%.Furthermore, calculated workload migration and consolidation could be identified to reduce power consumption with DRS. Cooling systems account for approximately 30 to 40 percent of overall data centre energy, while modern systems can minimise this by nearly 50 percent (Bharany et al. 2022) [referred to figure 2.5.1]. The advanced strategies comply with the green computing theory, which presents sustainable computing through resource utilisation. These significant strategies are crucial for accomplishing energy-efficient and sustainable cloud computing systems.

2. The innovative strategies to improve the energy efficiency of cloud computing systems

Diverse projects are underway to save energy in computing without reducing the amount of power or performance. A system with artificial intelligence can predict its needs and direct resources accordingly, leading to better results. The authors mention that this automation lets buildings use 40% less energy while maintaining quality (Park et al. 2023). Nowadays, more users are adopting serverless computing. They minimise energy use and assess resources in real-time by permitting code execution without equipping servers, which promotes scalability and efficiency. This model reduces the requirement for over-provisioned infrastructure while eliminating wasteful energy expenditure. These critical techniques comply with the sociotechnical systems theory while stressing an appropriate integration of process, technology, and people to maximise energy efficiency.

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Furthermore, some strategies are created, such as green scheduling algorithms to minimise the energy use of tasks or allocate data centre operations to sources of renewable energy (Park et al., 2023). These processes ensure that cloud services stay scalable and cost effective while helping achieve sustainability. Cloud computing is moving toward being more environmentally friendly and effectively managing recent operations.

3. The analysis of the current energy consumption of cloud computing infrastructures from major service providers

The primary cloud service providers, including Amazon Web Services, Microsoft Azure, and Google Cloud, are significant energy consumers when operating on a vast scale. According to Buyya et al., data centres that support these cloud service platforms consume between 1.5% and 2% of global electricity consumption. It has been observed that this consumption may double by 2030 without intervention [referred to Figure 3].

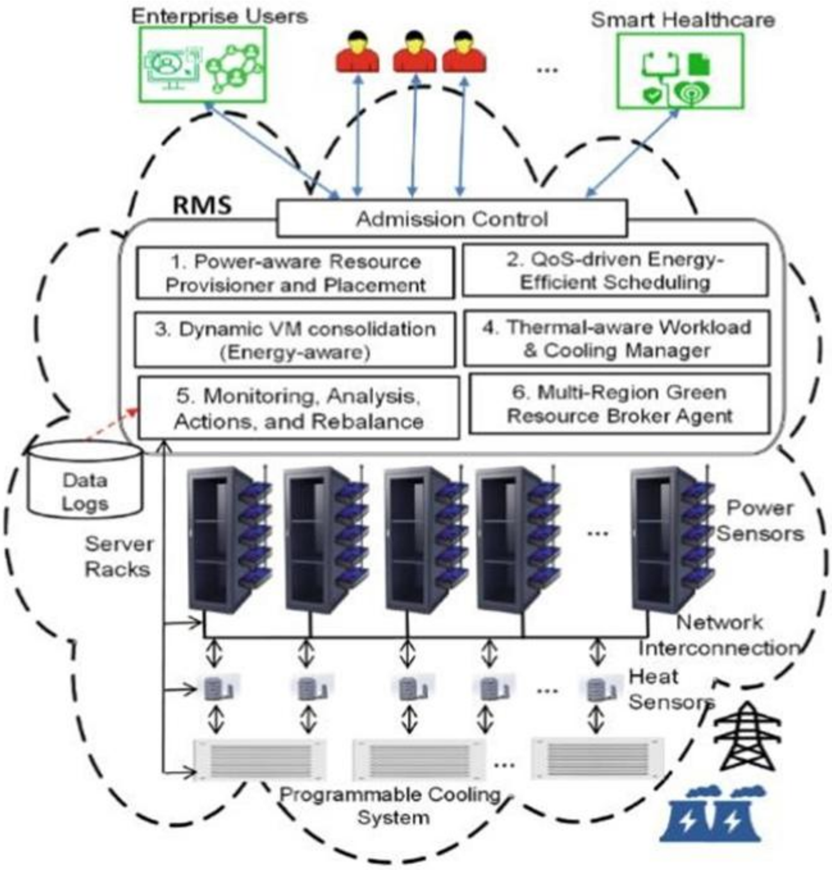

Figure 3: Resource management system of a data center

Katal et al. (2022) point to 'energy consumption' deriving partly from the servers, storage devices, and network components with inherent inefficiencies in the equipment, wasting a considerable proportion of electricity. The problem persists due to aging infrastructure and reliance on energy-consuming cooling systems. Furthermore, Islam et al. (2023) describe that despite hyperscale vendors bringing renewables and working on more efficient energy use with workload migration and advanced analytics, cloud demand is growing exponentially, counteracting these factors. Despite diverse efforts, energy consumption is still high, indicating the necessity for more integrated approaches to minimising environmental impact while preserving scalability.

4. Theoretical underpinning

'Green Computing Theory' and 'Sociotechnical Systems Theory' offer applicable methodologies for improving 'energy efficiency in cloud computing environments'. 'Green Computing Theory' engaged individuals in conscientious computing to reduce environmental footprints and engage in sustainable efforts such as

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renewable energy use, designing energy-efficient hardware, and utilising energy-efficient software systems (Nazaré et al. 2023). 'Sociotechnical Systems Theory' promotes the balanced interplay of technology, human actors, and organisational structure in decision-making. This theory supports integrated approaches that implement technical innovation while evaluating human connectedness to deliver improved system efficiency, sustainability, and cheap production of services (Münch et al. 2022). These theories comprise an integrated approach to a scalable, holistic, sustainable cloud infrastructure.

5. Literature gap

Many papers detail energy-saving methods in cloud computing. However, there is a gap in the literature regarding a unified approach using energy-efficient solutions across the software, infrastructure, and systems, and on real-time artificial intelligence-supported optimisation modelling to realise sustainability and performance across diverse scaling cloud architectures.

RESEARCH SIGNIFICANCE

This study is significant as it meets the increasing demand for sustainable and energy-efficient cloud computing infrastructures. It enables cloud service providers and policymakers to make strategic decisions regarding global sustainability and preserve digital services' performance and scalability. It can also help reduce environmental pollution, decrease operational costs, and assist in greening technology by identifying inefficiencies and providing innovative solutions.

METHODS

1. Research philosophy

Positivism is based on the preference for objective, measurable observations and empirical evidence to grasp reality (Saliya, 2023). In the context of this study, it enables the analysis of 'energy efficiency in cloud computing' by considering performance metrics and measurable data. This method is suitable as it creates an objective assessment of technology-related strategies, ensuring reproducible outcomes while enhancing the study's legitimacy.

2. Research Design

A descriptive research design aims to analyze a phenomenon systematically using objective and systematic information (Ansari et al. 2022). This study has taken a 'descriptive research design' approach to measure the level of current energy-efficient strategies in cloud infrastructure. This design is suitable for explanatory research as it accurately depicts current practices, understanding the trends and gaps without manipulating the variables. This helps to provide factual observations and real-world representations.

3. Research approach

Deductive approach assists in drawing conclusions based on structured data analysis that inherently tests existing theories or frameworks (Mulisa, 2022). It validates existing energy-saving concepts for cloud computing. This method is feasible since it provides a critical structure for objective-based assessment. It promotes a consistent, theory-led inquiry that is consonant with positivism and reflective of the quantitative nature of the study.

4. Population

The population in research includes the relevant resources to be enhanced so that the information needed for study objectives can be gathered and examined. The primary data for the research has been collected from 31 individuals. Of 31 people surveyed, each was involved in the cloud and IT sector.

5. Sample size

The 'sample size' for the research is 31. Primary data from 31 individuals involved in the cloud and IT sector has been gathered. Convenience sampling was employed, through which respondents with different exposure to cloud computing and associated fields were sampled.

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6. Sampling technique

The research recruited available participants who could respond through a Google Form. In this regard, a non-probability sampling technique was used to collect data in a relatively short period for the refined research.

7. Data Collection Method

The 'data collection method' sheds light on the particular source types for gathering relevant data to meet the requirements of the study (Mazhar et al., 2021). The quantitative data was collected from an online Google Forms survey. The study contains two demographic questions and eight Likert scale statements around the attitude and behaviour of cloud computing infrastructure for energy-efficient use. The results were analysed in terms of themes to support energy-efficient technologies.

8. Data Analysis Method

Data analysis is the 'systematic process' to clean, examine, and analyse data to obtain 'useful information and conclusions' (Hosseinzadeh et al., 2023). The visual analysis of demographic data distribution and the Likert scale was conducted utilizing bar and pie charts by data visualization tools. This provided a systematic examination of the trends and patterns of energy perception in the cloud computing infrastructure to ensure reasonable, objective conclusions and comparisons of the quantitative results.

9. Ethical consideration

Informed consent must be obtained from participants who understand the research's scope, significance, and purpose, ensuring ethical integrity. All the participants were volunteers and could leave the study at any point. This study adhered to the data protection ethics, allowing for good data collection and preventing individuals from accessing this information. This study has been transparent in all reporting and analysis of the data without distortion or bias in the presentation of the findings.

RESULTS

1. Data analysis

This section summarises the results of our study of existing energy-efficiency solutions in cloud computing infrastructures. Key design principles, performance results, and implementation practices of state-of-the-art technologies are discussed while providing an understanding of how these techniques effectively achieve efficiency, sustainability, and scalability in data centres in the cloud era.

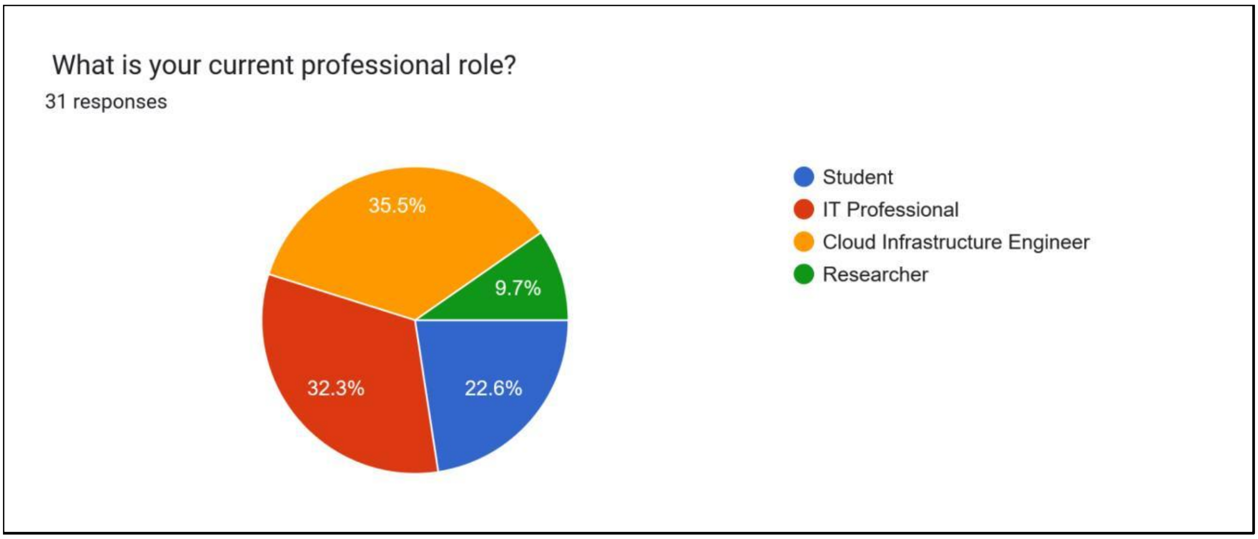

Figure 4: Professions of participants

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It can be observed from the above diagram that the majority of the study participants are cloud infrastructure engineers, which constitutes 35.5%. Others are IT professionals (32.3%), researchers (9.7%), and students (22.6%).

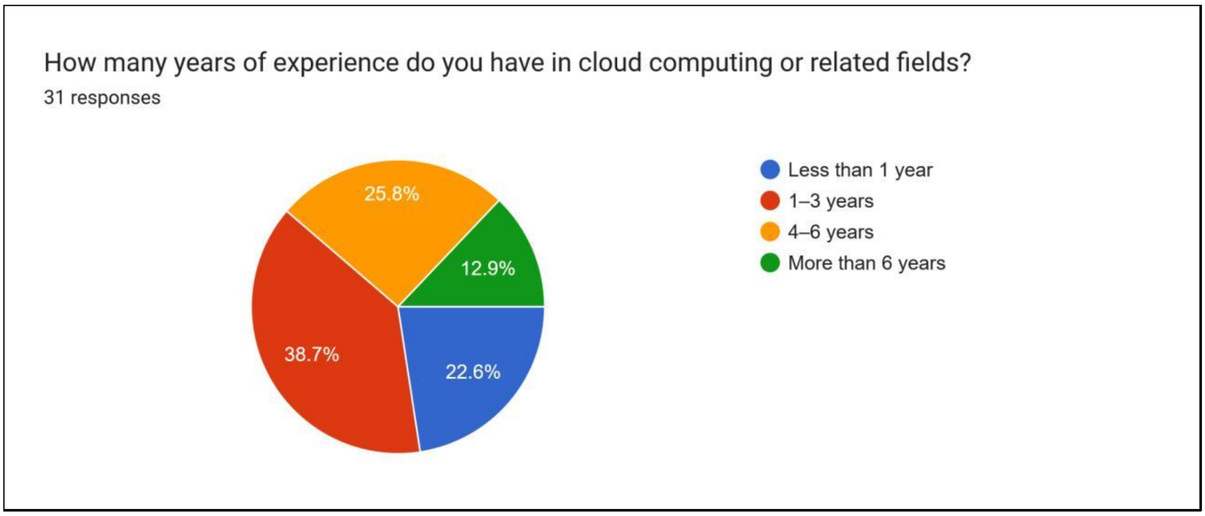

Figure 5: Experience of participants

From the above figure, it can be seen that the majority of the selected participants have 1 to 3 years of experience in their respective fields, constituting 38.7%. On the other hand, 12.9% of participants have more than 6 years of experience.

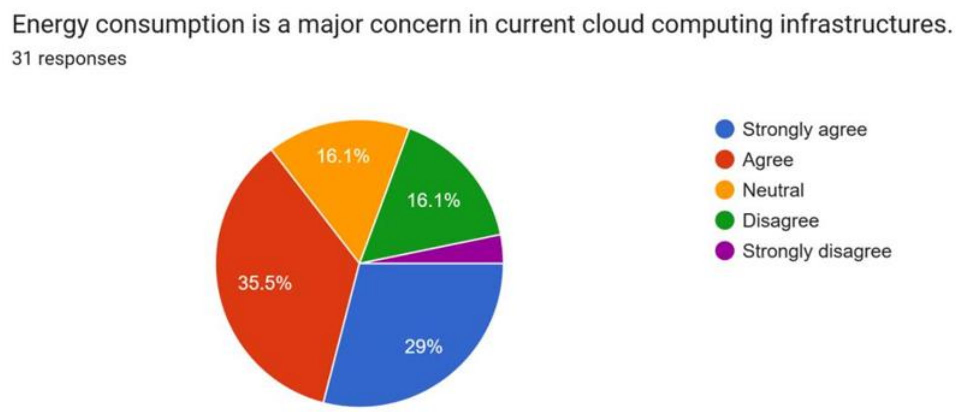

Figure 6: Concern related to energy consumption

38.5% of the participants agreed that 'energy consumption' is a significant concern in the present cloud computing infrastructure, while 16.1% disagreed. High energy consumption in cloud computing has enhanced operational and environmental concerns due to increased infrastructure demand and carbon emissions.

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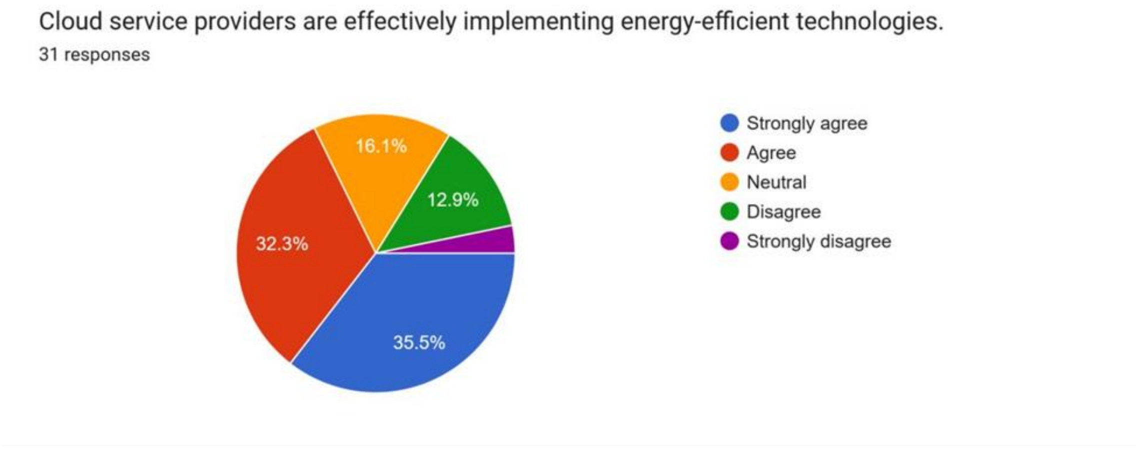

Figure 7: The implementation of energy-efficient technologies

A total of 35.5 % of participants have strongly agreed that cloud service providers are efficiently integrating energy-efficient technologies. Contrarily, 12.9% of participants disagree as they do not think cloud service providers have a role in energy-efficient technologies. Saleem et al. (2023) highlight how modern innovations improve sustainable operations while reducing energy waste in cloud-based infrastructures.

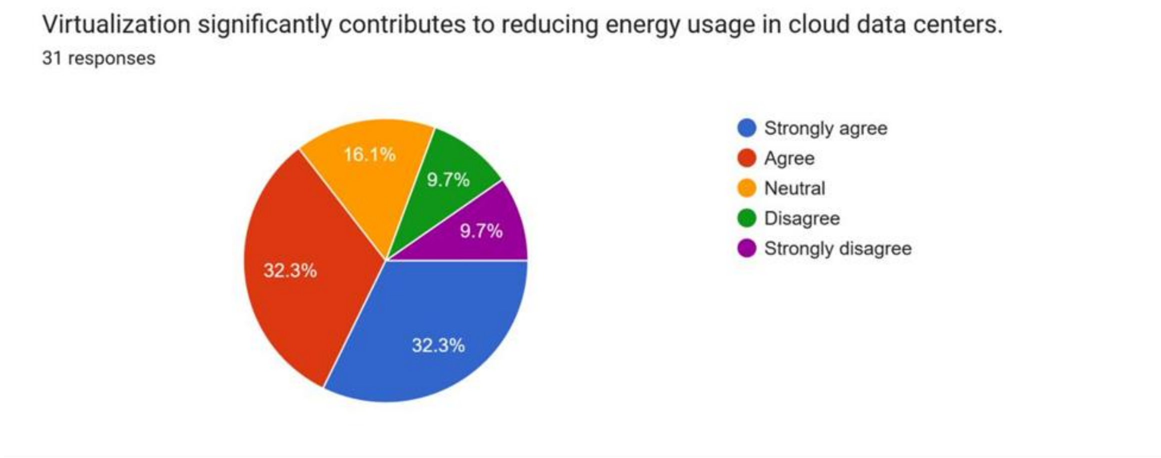

Figure 8: The role of virtualisation in reducing energy consumption

Most participants, including 32.3%, have strongly agreed that virtualisation significantly contributes to the minimisation of 'energy usage in cloud data centres'. In this context, Ahmed et al. (2021) stated that virtualisation assists in reducing extra resource usage, which enhances 'energy efficiency' and lessens the power demand of cloud data centres.

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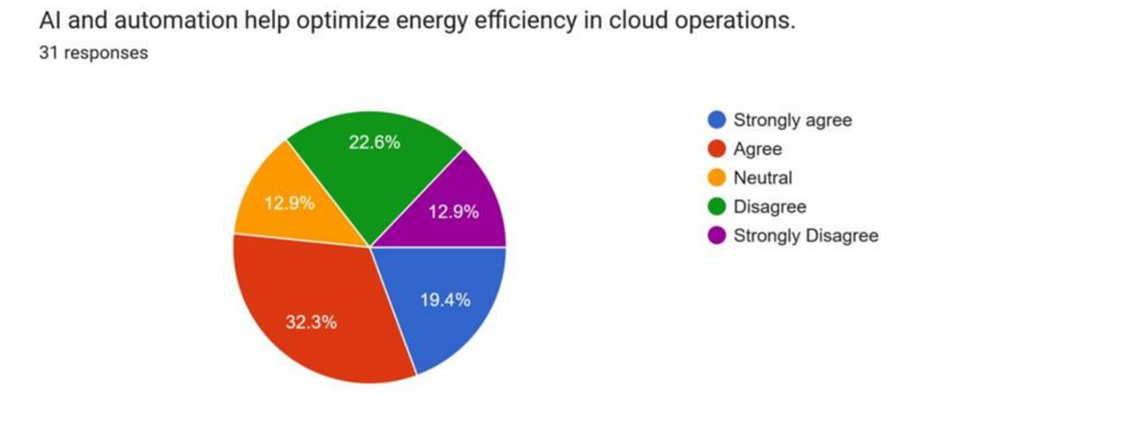

Figure 9: The optimisation of energy efficiency

It can be observed from the above figure that 32.3% of participants agreed with the fact that automation and artificial intelligence assist in maximising energy efficiency in cloud operations. These significant technologies enhance system responsiveness, assist sustainability goals, and reduce wasted energy. Automation and artificial intelligence assist in making decisions based on real-time data, which improves energy conservation efforts and performance of data centres.

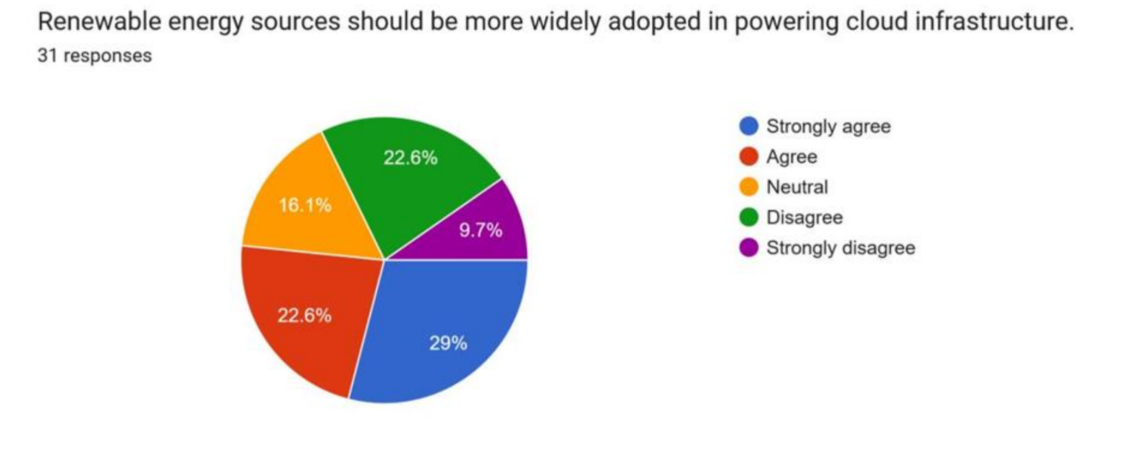

Figure 10: The adoption of renewable energy sources

From the above figure, it can be observed that participants strongly agreed (29%) that renewable energy sources need to be more widely integrated in powering cloud infrastructure. Yet, it necessitates addressing grid integration, variability, and storage challenges to ensure consistent scalability.

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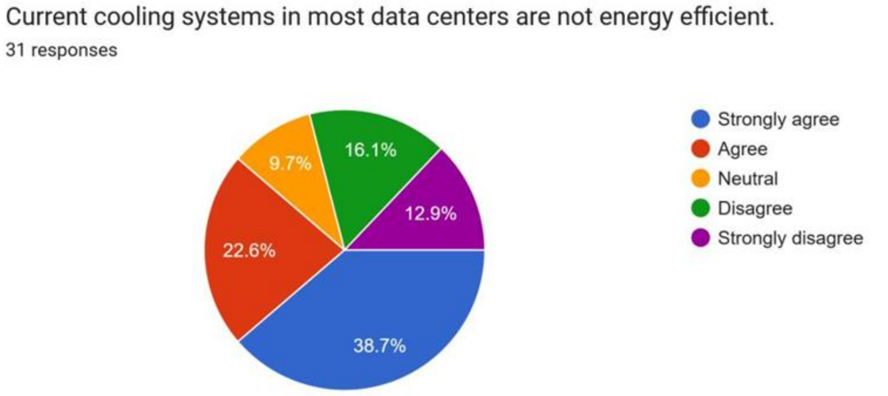

Figure 11: The role of cooling systems in data centres

It can be observed from the above figure that a total of 38.7% of participants have strongly agreed that the current cooling systems in the majority of data centres are not typically energy efficient. Modern cooling technologies, including artificial intelligence-based thermal management and liquid cooling, minimise energy consumption while improving sustainability within cloud infrastructure. Therefore, cooling systems are significant in managing optimal temperatures in cloud data centres, directly influencing system reliability and energy efficiency.

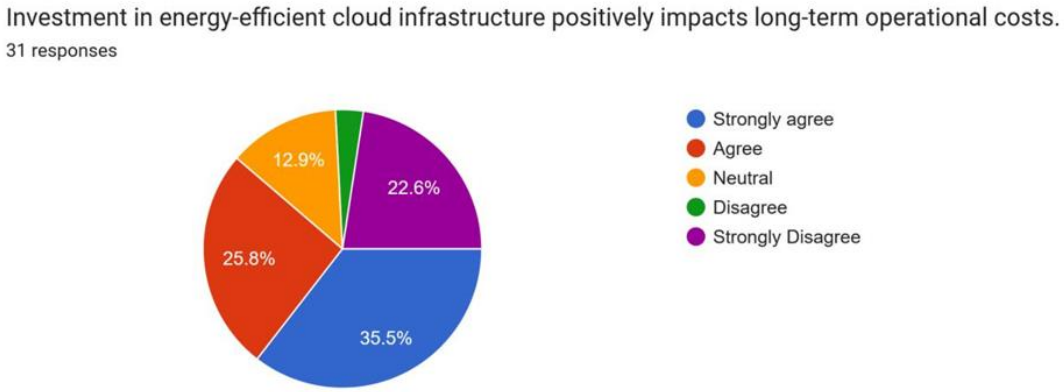

Figure 12: The investment in energy-efficient cloud infrastructure

It can be observed from the above figure that 35.5% of the participants have 'strongly agreed' with the fact that investment in energy-efficient cloud infrastructure significantly influences operational costs. Systematic investment in advanced cloud infrastructure eliminated operational costs by reducing energy consumption. Venkateswaran et al. (2023) argued that advanced energy management strategies in cloud systems help to save extra expenditure while assisting sustainability through minimising energy waste and carbon footprints.

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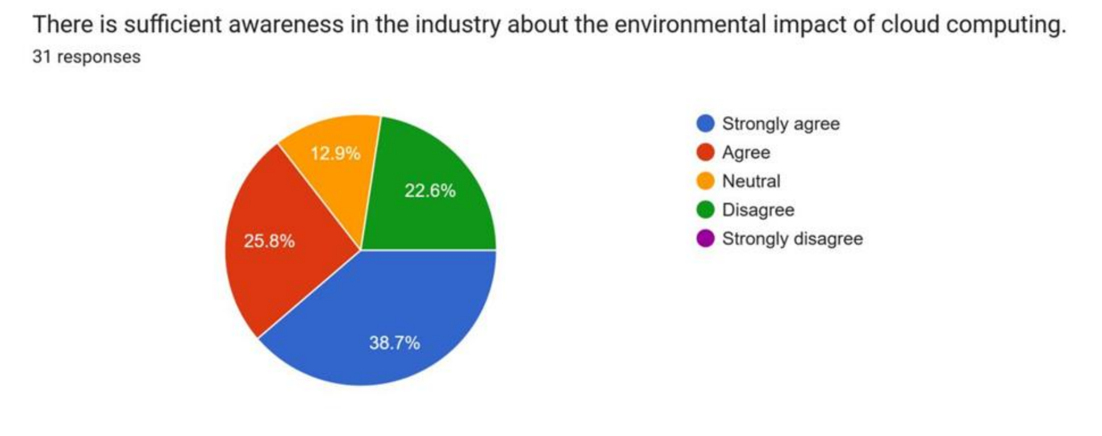

Figure 13: The awareness about the environmental effects of cloud computing

From the above figure, it can be observed that 38.7% of participants strongly agree that there is sufficient awareness in the industry regarding the environmental influence of cloud computing. A study by Shekhar & Aleem highlighted that determining cloud operations' energy demands and carbon emissions is significant in integrating advanced energy-efficient solutions in information technology cloud environments to enhance sustainability.

2. Findings

The insights obtained in this paper present a high awareness and increasing concern among professionals about 'energy consumption in cloud computing' facilities. Many respondents (38.5%) considered energy exploitation as an issue that adversely affected the operating efficiency and the environmental aspect. The result indicates that green energy-saving technologies are being implemented by the 'cloud service providers', and 35.5% of participants agree that cloud service providers are working to implement this trend. Similarly, Saleem et al. (2023) stress the importance of technological advances in energy management.

Virtualisation was identified as a significant contributor to energy efficiency, with 32.3 percent indicating that there were benefits to reducing the energy requirements of a data centre using virtualisation. Similarly, automation and artificial technologies were demonstrated by 32.3 percent of participants to provide energy savings by supporting real-time decisions that improved performance. The use of renewable energy obtained support from 29 percent of participants, even with the practical challenges remaining. There was significant agreement that a majority (38.7%) felt that their current cooling systems were inefficient, raising concerns about what would represent modern thermal management. Investment in energy-efficient infrastructure was viewed as a cost-effective approach by 35.5% of participants, highlighting the credibility of the costs associated with its environmental benefits. Lastly, 38.7% of participants agreed that awareness is there about the 'environmental impact of cloud computing' and that it is an encouraging sign towards sustainability in the cloud ecosystem.

DISCUSSION

1. Interpretation of the Results

Based on the above result, it can be comprehended that respondents have highlighted perceptions of energy efficiency in cloud computing infrastructure. A high proportion of respondents either strongly agree or agree that energy efficiency is an important issue, implying that such environmental and operational issues of power consumption of cloud data centres are much more perceived. However, there were mixed responses on whether cloud service providers actively adopt low-energy technologies, indicating a wide gap between awareness and implemented actions. Most respondents have felt that virtualization and AI-based automation play a positive part in adopting energy optimization, and indicate awareness of the role of advanced technologies in

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minimizing consumption. The position on the uptake of renewable electricity was initiated with a high level of support, such as acceptance from the public and professional equality that cloud operations require sustainable power. On the other hand, a specific group of respondents did not agree that cooling systems in data centres are efficient, highlighting an area of potential inefficiency where old-fashioned infrastructure could be irrelevant to current energy standards. The optimistic assessment of long-term economic savings from energy efficiency is based on a well-established awareness of the economic motives behind sustainable practices. Finally, the responses to industry understanding of environmental impacts are mixed, reflecting that while some progress has been made, further opportunities exist to get sustainability into cloud infrastructure.

2. Linking with Research Questions and Literature

The study results have confirmed the literature review regarding energy efficiency in cloud computing infrastructure. The survey results must show a strong linkage regarding the importance of energy, which aligns with the assessment of Buyya et al., which estimated that cloud data centres consumed up to 2% of global electricity consumption. The necessity of virtualisation was agreed upon in responses, which is a well-established approach along with the findings of Panwar et al. (2022), indicating the mitigation of machine dependency and improved resource utilization. On the other hand, respondents also demonstrated that AI and automation would be instrumental in efficiently using energy. These findings are consistent with the literature of Park et al. (2023), who showed that intelligent systems can decrease energy consumption by 40%. In the literature, cooling systems were also pointed out as an essential source of inefficiencies, affirmed by the participants' concerns towards old or inefficient cooling infrastructures.

This study validates the industry's acceptance of renewable energy exploitation and green scheduling algorithms, such as minimizing energy consumption while scaling through workload. Mixed attitudes towards the effectiveness of current applications lead to a disconnect between the technical potential and the level of use in practice. This supports the assumptions Islam et al. (2023) made that the trend towards higher cloud demand counteracts many energy-saving measures despite advancements.

3. Implications, Limitations, and Potentials for Future Research

This research has demonstrated the increasing trend of cloud service providers adopting energy-efficient strategies such as virtualisation, AI-based optimisation, and integrating renewable energy sources. The results suggest greater overall industry adoption of these methods, which could enable significant energy savings and operational benefits. However, limitations include small sample size, self-report bias, and limited geographical representation. These potential limitations may limit the generalizability of the findings. The sample size can be expanded in the future by involving multiple participating stakeholders in different regions and using mixed approaches to get deeper information. Furthermore, long-term studies might investigate the implications of new technologies and green computing techniques on cloud computing infrastructures' energy efficiency, performance and environmental sustainability.

CONCLUSION

It can be concluded from the above discussion that the relevance of cloud computing infrastructure encompasses energy efficiency, covering typical and innovative energy-efficient strategies as well as the consumption trends between the largest service providers. The results highlighted virtualization, dynamic resource scheduling, AI optimization, and renewable energy usage to ensure energy efficiency and sustainability of data centres in sustainable management. The participants also agreed that immediate actions are needed to create more efficient cooling systems and mitigate potential issues within the industry. These findings are consistent with prior studies and affirm the use of green computing and sociotechnical systems theory. The work highlights the importance of sustainable integrated approaches to the elevated energy demands in cloud environments. Moreover, consistent investment also needs to be made in developing efficient solutions that progress into actual deployment. The impact of these findings is essential as they can be used to guide policymakers, cloud providers, and researchers to make cloud computing systems more sustainable and efficient.

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