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Green cloud computing for renewable energy: A study on Energy efficiency and carbon footprint reduction

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Abstract: Cloud computing has rapidly expanded and generated environmental concerns in terms of energy consumption and greenhouse gas emissions. The paper investigates the possibilities of green cloud computing in conserving power and carbon production. Green cloud computing reduces an organization's carbon footprint, decreases power costs, and ensures a better future using energy-efficient technologies, renewable resources, and sustainable practices. This study intends to help to the literature about green cloud computing field and find out some ideas in terms of sustainable development for cloud computing solutions. In this study, 3 case studies AWS (Amazon Web Service) Case Study 1: Applica's AI-Powered Content Moderation, Case Study 2: Google Cloud Sustainability Initiatives and Case Study 3: Microsoft Azure Sustainability Initiatives are analysed and compared the gaps in present implementation of cloud computing and suggested some of the measures to overcome.

Keywords-- Green cloud Green cloud computing, energy conservation, carbon reduction, green sustainability, cloud computing

INTRODUCTION

Cultivate the Whole Garden of Cloud Computing But at the same time as cloud computing developed quickly, people began to give on-demand access to computed resources through the internet. All this was not even possible a few years ago [1]. Cloud computing is an inseparable aspect of modern computing as far back as 2020, with over 90% of companies using cloud service [2]. Yet at the same time as it has expanded, it too has brought in new problems surrounding the environment: its heavy energy consumption and production of large quantities of greenhouse gases [3]. The backbone of the cloud infrastructure, data centres consume a great deal of energy. Their electricity consumption is estimated at about 1% of global production [4].The world's cloud computing industry generates, approximately 1.4 billion metric tons of CO2 equivalent, each year. With the increasing demand for cloud services, driven by the continuous expansion of digital technologies such as artificial intelligence, big data, and the Internet of Things (IoT) [5], the impact on nature from cloud computing so far is never enough to just be described by words. It is not just because of a problem with current technology but also something else: indeed there seems, no other way around this other than that technology takes the lead in solving what it itself has created! Green cloud computing is a key solution, paying attention to energy conservation and carbon reduction [6]. Green Cloud computing involves the application of energy-efficient technologies, renewable energy sources and sustainable use to lower the environmental impact [7]. Through the use of green cloud computing, businesses can reduce their carbon footprint, lower power costs and contribute to a sustainable tomorrow. The study explores the potential of green cloud computing for saving energy and reducing carbon emissions, and looks for solutions that can guarantee production of infinitely sustainable industry. The study is intended to make its own aims to make a small but meaningful addition towards the increasing amount of studies on green cloud computing, and at the same time to help provide ideas for sustainable development of cloud computing solutions.

II.LITERATURE REVIEW

The rapid development of cloud computing is causing more and more people to be worried about its environmental impact including energy consumption and greenhouse gas emissions [8]. Therefore, many ways have been developed in relevant research to reduce such worries and take account of effects such as data centres that save energy, the use of green-powered high-tension electricity lines for running servers on mountain peaks above major urban areas, or sustainability in cloud computing practice as a principle.

i. Energy Efficiency in Cloud Computing: Corresponding studies have shown that using energy-efficient data centres can reduce both electrical power consumption and carbon emissions However, improvements such as virtualization dynamic voltage and frequency scaling consolidation etc. have been

proposed to increase the energy efficiency of live data centers. Unfortunately, these can also make a system more complicated with attendant problems that affect performance [9].In recent years there have been a number of studies aiming to get the best energy usage in large cloud computing systems. For example, machine learning algorithms have been used to predict energy consumption [10].

ii. Renewable Energy Sources: Use has been made of renewable energy sources, such as solar and wind power, to reduce the reliance on fossil fuels and slow down the state of carbon emissions. For integrating renewable energy sources into the cloud computing infrastructure, researchers suggested a variety of frameworks and architectures [11]. However, the lack of continuity in the renewable energy sources presents a problem for cloud computing. Solutions will need to be highly automated management and storage systems for electricity. Then recent studies on the use of energy storage systems, such as batteries, to overcome the discontinuity of renewable energy sources.

iii. Green cloud computing: "A very substantial amount of research has been done on making cloud computing more environment friendly." Some studies have addressed different aspects of green cloud computing, such as energy–efficient resource allocation carbon- constrained scheduling [12] or how to operate in a way worthy of "sustainable development" Nonetheless, further research is needed in order to construct more comprehensive models which consider multiple elements of sustainability in Green Computing). Recent study also deals with sustainable cloud computing frame.

iv. Main contribution: Through previous research has yielded much of value, there are still limitations and bottlenecks. For example, it is common in many studies to focus only on one facet of green cloud computing--for example, energy efficiency Likewise, some researchers concentrate on renewable [13] But in reality a more thorough approach is needed that encompasses various metrics of sustainability . if we are to fully understand what harm cloud computing might do to our world. At the same time, we have to keep an eye on the future, for we are still far from delivering scalable and efficient green cloud-computing models for general use by cloud providers. The three case studies of these three providers (AWS, Google Cloud and Microsoft Azure) were just those that have leading cloud computing providers that are very much committed to sustainability and have made great innovations in green cloud. Through their practices, plans and results, I can obtain insights of great value for the current situation regarding cloud computing and also help organize benchmarks which are most to be used in future studies of this kind. The cases show the full effort major cloud providers are making to lessen environmental harm caused by cloud computers and facilitate sustainable practices in clouds.

III.METHODOLOGY

This study adopts a comprehensive mixed-methods approach, merging quantitative and qualitative methods to investigate sustainable cloud computing practices. The methodology is designed to capture the complexities of cloud computing adoption, providing a nuanced understanding of the drivers, challenges, and opportunities.

A. AWS Case Study 1 : Applica's AI-Powered Content Moderation

Applica, a Poland-based company, is using Amazon Web Services (AWS) to power its artificial intelligence (AI)-based content moderation algorithms.[14] The platform processes over 4 million posts each month in 96% accuracy, comparable to the level of human moderators.

1. Key features

Auto Scaling: The system automatically scales infrastructure required to handle varying workloads, guaranteeing high availability and cost efficiency.

Amazon Elastic Compute Cloud (Amazon EC2): Offers flexible capacity within a highly dependable infrastructure.

Amazon Simple Storage Service (Amazon S3): Main data store for efficient management of units.

Elastic Load Balancing: Through this service traffic is automatically distributed between instances for smooth and stable performance.

2. Long-term effects of the use of aws for ai-powered content filtering

- Expanding The ability to deal with 10 times its normal load, without any problems. This means that high performance and reliability are guaranteed.

Adapted to change: Auto Scaling keeps Applica from being vulnerable to peak workloads. It can reduce the chance of outages and raise overall interaction efficiency.[15]

- Cost-effectiveness Lower costs: because of the pay-as-you-go pricing model, costs for Applica and its customers will be lower. Business can be more competitive and sustainable.

More efficient distribution of resources: AWS offers cost-effective infrastructure, which means Applica can focus its resources more effectively on innovation and development.[15]

- Fast Update Smooth performance: Elastic Load Balancing ensures continuous performance through updates which reduces downtime, all while being more cost effective.

Better maintenance: On AWS infrastructure, Applica's maintenance services are completely smooth and error free so that even the most complex software will be handled

effortlessly without disrupting operations or leading to any mistakes.[15]

- High Accuracy State-of -the-art AI services: Applica's AI-powered moderation platform provides content that is of a high accuracy which is equal to human labor standards. This alone improves service quality across the board.

Better customer satisfaction: High accuracy and security improve customer satisfaction, shortening the time of putting out fires in drastic cases. [15]

3. Limitations on data on sustainability

- AWS Focus: this does not represent Amazon's general sustainability performance.
- Implementing Challenges: Extending sustainability programmes worldwide.
- Technological limitations: Now, sustainable technologies are not enough.
- Regulatory Uncertainty: Regulations in environmental matters are at a still-evolving stage.
- Complex Supply Chain: Dependence upon suppliers and partners.

B. case study 2: google cloud sustainability initiatives

As early as 2022, Google Cloud had entered into sustainability, noting that its target for 2030 was neutrality in carbon emissions (Google 2022) [16] This noble aim illustrates the company's commitment to minimizing its environmental impact and enduring environmentally friendly practices. This case study shows how Google Cloud pursues carbon neutral through investments in renewable energy, now serving 75% of total consumption this way; energy-efficient infrastructure development increasingly becomes the norm as well.

1. Key features

Carbon Neutrality Goal: Google Cloud launched an ambitious project to achieve carbon neutrality by 2030 through its various objectives.

Renewable Energy Investments: with its support for renewable energy projects such as solar and wind farms [17]

Energy-Efficient Infrastructure: Wisely, it only cools the data centers that are hot and uses energy-efficient servers and cooling systems.

2. Long-term impacts from Google Cloud initiatives for sustainability

- Reduced carbon footprint

Google Cloud's sustainability initiatives aim to significantly reduce the carbon footprint of its operations, by cutting greenhouse gas emissions right down at their source. This is achieved through:

- Energy-efficient infrastructure: Energy-efficient data centre, server and cooling system usage in built or specially designed low-energy facilities all helps to cut demand by 30% to 50%
- Investing in renewable energy project: The company has already invested in both solar and wind power, with a view to expanding this to other sources such as biofuels or geothermal energy in future decades. Google Cloud produces no carbon itself but by reducing the carbon footprint associated with its use, it helps make global warming slower and cleaner than would otherwise be possible.

- Increased use of renewable energy

Google Cloud's goal is to increase the proportion of power for its operations provided by sources that are replenishable, such as:

Solar energy: Investing in solar farms and panels to power data centers.

Wind energy: Further funding wind farms for generating electricity.

Other renewable energy sources: Exploration of other renewable energy sources, such as hydroelectricity. By increasing its use of renewable energy, Google Cloud is reducing the market impact of fossil fuels and minimizing its effects on the environment.

- Policy as a benchmark

Google Cloud's promotional efforts in sustainability as a benchmark for technical businesses.[18] For example: Demonstrating commitment to environmentalism: Articulating a position on corporate responsibility and showing its actual implementation.

Innovating sustainable solutions: Researching new methods to reduce environmental impact.

- Enhanced Brand Reputation

For Google Cloud, the advocacy of sustainability has been an opportunity to boost its brand reputation. By demonstrating that it is an environmentally responsible outfit, Google Cloud proudly flaunts the fact that it cares about reducing its effect on the natural environment.

In view of strong environmental commitment from its past customers, Google Cloud builds up trust. Sustainability initiatives contribute to a positive brand image, resulting in greater brand value. Google Cloud builds trust with customers and shareholders by sticking to sustainable policies.

- Cost Savings

Business/Product doesn't tell me how this actually will help the industrial consumers.

Google Cloud's use of sustainable measures can result in potential savings of costs.

Energy efficiency- with streamlined business processes and the latest technologies.

Renewable energy-Since investment in renewable energy communities can lead to lower fixed costs.

3. Limitations in the case study: google cloud sustainability initiatives

- Limits of Data: Lack of panoramic access to detailed sustainability data.
- Limits to Scope: When it comes to Google Cloud, the cases made are not tangible representations of Alphabet Inc. nor industry at large.
- Challenges of Implementation: From the local scale to that of a global giant.
- Constraints of Renewable Energy: Regional differences in the availability of renewable energy sources.
- Uncertainty of Regulation: As environmental regs evolve.[20]

C. Case Study 3 : Microsoft Azure Sustainability Initiatives

Microsoft Azure is looking forward to the day when 60% of its cloud computing facilities are powered by renewable energy (Microsoft, 2022).[19] This case study explores the efforts of Microsoft Azure at Greener solutions for low carbon industries and high energy consumption enterprises. Innovation in green IT ways to improve services and reduce demand on data centers as well as problems cloud computing might bring such as air pollution to you!

1. Key features

Renewable Energy: To invest in renewable energy projects powering data centres.

Efficient Data Centers: To design and operate energy efficient data centres.

Environmental Protection Projects: Carry out programmes to reduce energy consumption and waste.

2. long-term outcomes of microsoft azure sustainability initiatives

- Reduced Carbon Footprint

By actively making an effort to reduce its carbon footprint, Microsoft Azure's suite of sustainability initiatives contributes to a cleaner environment and to the actual mitigation of climate change.

- Increased Use of Renewable Energy The company's investments in renewable energy projects, including solar power plants and wind energy facilities, will cause it to use ever more clean energy sources and little or none fossil fuels.
- Enhanced Reputations Microsoft Azure A voice against sustainability will enhance its brand reputation by exhibiting a commitment to environmental responsibility. This is attractive even crucial to customers and stakeholders who have sustainability on their list of important issues.

3. Limitation of case study: Microsoft sustainability initiatives

- Data Limitation: Sustainability data and metrics are difficult to capture.
- Implementation Challenges: Where Microsoft now has a global operation.
- Technological Constraints: Sustainability technologies now lack (are inadequate).
- Regulatory Uncertainty: Environmental regulations and policies are in a constant state of development.
- External Factors: This best practice depends on external factors such as trends in the energy market.

These limitations make it clear that further investigation and thought are needed across multiple fields.

IV. CONCLUSION & FUTURE SCOPE

This study looks into the practicality of using green cloud computing techniques to cut down on both power consumption and carbon dioxide emissions. We conducted a comprehensive analysis on three different case studies (AWS, Google Cloud and Microsoft Azure) and found both common elements as well key features, benefits and shortcomings of green cloud computing operations. The results show that green cloud computing can make a substantial contribution to alleviating a company's carbon footprint. Renewable energies are used more and the corporate image is improved. However, there are still some practical problems to be solved: data is being limited; how it gets implemented and whether there will be regulatory uncertainty with this new technology has yet been sorted out.

Future sustainability generating patterns

In the future, there needs to referee out integrated models that consider many facts of sustainability within cloud computing.

Exploring emerging techniques: Learning about the possibilities of new technologies such as AI, blockchain and IoT in aiding sustainability within cloud computing.

Establish measures: The programme establishes indicators and standards for measuring how green cloud computing operates.

Industry–higher education cooperation: Promoting cooperation between industry and academia to form a more sustainable way forward for clouds.

V. REFERENCES

[1] Radu, L. D. (2017). Green cloud computing: A literature survey. Symmetry, 9(12), 295.

[2] Xu, M., Toosi, A. N., & Buyya, R. (2020). A self-adaptive approach for managing applications and harnessing renewable energy for sustainable cloud computing. IEEE Transactions on Sustainable Computing, 6(4), 544-558.

[3] Radu, L. D. (2017). Green cloud computing: A literature survey. Symmetry, 9(12), 295.

[4] Gill, S. S., & Buyya, R. (2018). A taxonomy and future directions for sustainable cloud computing: 360 degree view. ACM Computing Surveys (CSUR), 51(5), 1-33.

[5] Varghese, B., & Buyya, R. (2018). Next generation cloud computing: New trends and research directions. Future Generation Computer Systems, 79, 849-861.

[6] Garg, P. (2016). A green step towards computing: Green cloud computing. International Journal of Research, 5(2), 3-9.
[7] Yang, J., Xiao, W., Jiang, C., Hossain, M. S., Muhammad, G., & Amin, S. U. (2018). Ai-powered green cloud and data center. IEEE Access, 7, 4195-4203.
[8] Radu, L. D. (2017). Green cloud computing: A literature survey. Symmetry, 9(12), 295.
[9] Bharany, S., Sharma, S., Khalaf, O. I., Abdulsahib, G. M., Al Humaimeedy, A. S., Aldhyani, T. H., ... & Alkahtani, H. (2022). A systematic survey on energy-efficient techniques in sustainable cloud computing. Sustainability, 14(10), 6256.
[10] Khan, T., Tian, W., Zhou, G., Ilager, S., Gong, M., & Buyya, R. (2022). Machine learning (ML)-centric resource management in cloud computing: A review and future directions. Journal of Network and Computer Applications, 204, 103405.
[11] Islam, M. S., Al-Amin, A. Q., & Sarkar, M. S. K. (2021). Energy crisis in Bangladesh: Challenges, progress, and prospects for alternative energy resources. Utilities Policy, 71, 101221.
[12] Bhattacherjee, S., Das, R., Khatua, S., & Roy, S. (2020). Energy-efficient migration techniques for cloud environment: a step toward green computing. The Journal of Supercomputing, 76(7), 5192-5220.
[13] Zeng, D., Zhang, J., Gu, L., Guo, S., & Luo, J. (2018). Energy-efficient coordinated multipoint scheduling in green cloud radio access network. IEEE Transactions on Vehicular Technology, 67(10), 9922-9930.
[14] https://aws.amazon.com/solutions/case-studies/Applica/
[15] Pandit, Pooja. (2021). A Case Study of Amazon Web Services. 10.13140/RG.2.2.18114.09921.
[16] Tim, H. W., & Rana, M. E. (2022, October). A Review of Cloud Computing on Sustainable Development: Contribution, Exploration and Potential Challenges. In 2022 International Conference on Data Analytics for Business and Industry (ICDABI) (pp. 176-183). IEEE.
[17] Oloruntoba, O. (2024). Green cloud computing: AI for sustainable database management. World Journal of Advanced Research and Reviews, 23(03), 3242-3257.
[18] Folkerts, E., Alexandrov, A., Sachs, K., Iosup, A., Markl, V., & Tosun, C. (2012, August). Benchmarking in the cloud: What it should, can, and cannot be. In Technology Conference on Performance Evaluation and Benchmarking (pp. 173-188).
[19] Berlin, Heidelberg: Springer Berlin Heidelberg. Sustainable Cloud Computing: Reducing Carbon Footprint-Emphasis on eco-friendly and sustainable cloud practices. Advances in Computer Sciences, 5(1).
[20] El Koshiry, A. M., Eliwa, E. H., Abdel Mohsen, N. A., & Khalil, S. S. (2025). The Impact of AI-Based Cloud Network Management on Microsoft Azure in Promoting Green Technology Awareness. Sustainability, 17(3), 1065.