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Cloud computing for sustainable development: An analysis of environmental, economic and social benefits

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A B S T R A C T

This research paper examines the role of cloud computing in promoting sustainable development. Cloud Computing (CC) has emerged as a transformative technology that has the potential to reduce the environmental impact of businesses and organizations, while also enabling economic growth and social development. The paper explores the environmental benefits of cloud computing, including energy efficiency, reduced carbon emissions, and the potential for renewable energy integration. It also examines the economic and social benefits of cloud computing, including cost savings, increased productivity, and improved access to technology. The paper concludes by highlighting the potential challenges and opportunities associated with the adoption of cloud computing for sustainable development and identifies key areas for future research and policy action. Overall, the paper argues that cloud computing has the potential to play a critical role in promoting sustainable development, and that further research and policy action are needed to realize its full potential.

1. Introduction

Cloud computing is a model that enables users to access these resources quickly and easily without having to manage the fundamental substructure. CC providers typically offer different service models out of which infrastructure services rented virtualized computing resources such as servers, storage, and networks from the provider. In platform services, the provider offers a platform for users to develop, test, and install their own requests. In software services, the provider delivers software applications to users over the internet (Chandramohan and Ramasamy, 2023). Users can quickly scale their computing resources active or downcast as desired, without having to invest in and manage their own physical infrastructure. This makes it easier and more cost-effective for businesses to respond to changing demands and opportunities (Ram et al., 2023). Cloud computing enables greater collaboration and remote work capabilities. Additionally, CC sources naturally offer high levels of security and reliability, with data stored in multiple locations and backups maintained regularly. In addition to the benefits mentioned earlier, cloud computing also allows for better resource utilization, as multiple users can share the same computing resources, reducing waste and improving efficiency (Ghasemi et al., 2023). This also enables smaller organizations to access the same computing power as larger organizations, democratizing access to technology. This eliminates the need for large upfront investments in infrastructure, making it more cost-effective for businesses of all sizes.

Another advantage of cloud computing is that it allows for easy data backup and disaster recovery. Providers typically offer multiple backup options, and data is stored in numerous locations, dropping the threat of records damage (Fatemi, 2022). In the occasion of a disaster or outage, data can be quickly restored from backups, minimizing downtime and ensuring business continuity. There are some potential drawbacks to CC, however. One concern is security, as data stored in the cloud may be vulnerable to cyber attacks or data breaches. Additionally, reliance on a single provider may lead to vendor

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lock-in, where it becomes difficult to switch providers due to the cost and complexity of moving data and applications (Sahoo & Goswami, 2024). It has become an integral part of modern technology and is projected to endure to grow and evolve in the upcoming years.

1.1. Sustainable Development of Cloud Computing

Sustainable development is important because it ensures that resources are used in a way that is environmentally, socially, and economically responsible (Rahman, 2022). Organizations can diminish the need for on-premises data centers, which can consume significant amounts of energy and contribute to carbon emissions. Additionally, cloud computing can support sustainable development by enabling remote work and collaboration (Goswami and Behera, 2021a). Cloud-based collaboration tools can also help to reduce paper waste and other forms of resource consumption. Sure, here are the additional details on how CC can contribute to sustainable development.

- **Energy efficiency:** Cloud data centers are typically more energy-efficient than on-premises data centers, as they can take advantage of economies of scale to optimize their energy usage (Sharifi, 2022).
- **Resource sharing:** CC enables multiple users to share and reduce the amount of hardware needed overall. This can help to reduce the amount of e-waste generated, as well as the carbon emissions associated with the production and disposal of hardware (Alam, 2022).
- **Scalability:** Scalability can help to optimize their resource usage and reduce waste. This can be particularly useful for businesses with variable computing needs, such as those in the retail or hospitality industries (Oke, 2021).
- **Disaster recovery and business continuity:** CC can help businesses to implement disaster recovery and business continuity plans more easily and affordably. By storing data and applications in the cloud, businesses can ensure that they have access to critical resources even in the event of a disaster (Nowicka, 2014; Jin, 2021; Qi, 2021).
- **Green certifications:** Many cloud providers have obtained certifications from third-party organizations that certify their environmental sustainability. These certifications can help businesses to identify cloud providers that are committed to environmental sustainability and responsible resource usage (Issa, 2010).
- **Data center efficiency:** Cloud providers are constantly innovating and improving their data center efficiency, through initiatives such as modular data center design, advanced cooling technologies, and energy-efficient hardware (Jia and Wu, 2022; Wang, 2022).
- **Big data analytics:** CC enables businesses to analyze areas for improvement in terms of sustainability and resource usage. Big data analytics can identify energy-saving opportunities in buildings or to optimize supply chain efficiency to reduce waste (Sahoo & Choudhury, 2022).

Therefore, CC has numerous benefits for sustainable development, including, green certifications, efficiency, virtualization, and big data analytics. By leveraging these benefits, industries and entities can help to create a more ecological future for all.

1.2. Visions of different international organizations on sustainable cloud computing

According to the United Nations, CC can contribute to sustainable development in several ways, including.

- **Energy efficiency:** CC can significantly reduce energy consumption and greenhouse gas emissions compared to traditional on-premise data centers. Cloud providers can take advantage of economies of scale to optimize energy use and improve the efficiency of their infrastructure (Nara et al., 2021).
- **Reduced hardware waste:** With the help of CC, organizations can reduce the amount of physical hardware they need to maintain their IT infrastructure. This can help minimize e-waste, which can have a significant impact on the environment (Oke, 2021).
- **Increased access to technology:** CC can help improve access to technology in developing countries by providing a more affordable and flexible way to access computing resources (Yu and Chiou, 2022).
- **Remote work:** CC has played a critical role in enabling remote work during the COVID-19 pandemic. This can help reduce the need for commuting and decrease carbon emissions associated with transportation (Issa et al., 2010a).
- **Sustainable business practices:** CC can enable organizations to adopt more sustainable business practices by facilitating collaboration and communication, reducing paper waste, and optimizing resource use (Ion & Gheorghe, 2014).

1.2.1. USA government policies on sustainable cloud computing

The US government has taken steps to endorse the usage of cloud computing in a sustainable manner. In 2010, the US government launched the Federal CC Strategy, which aims to promote the adoption of cloud computing in federal agencies and reduce the environmental impact of government IT operations (Dogo et al., 2019). Here are some of the key initiatives taken by the US government.

- **The Federal Data Center Consolidation Initiative (FDCCI):** This initiative launched in 2010, aims to lessen the quantity of data centers used by the federal government and promote the adoption of energy-efficient technologies. The initiative is expected to save billions of dollars in energy costs and reduce the government's carbon footprint (Qi, 2021; Issa et al., 2010b).
- **The Green government initiative:** This initiative, launched in 2009, aims to promote sustainable practices in federal government operations, including the use of energy-efficient technologies (Ghasemi et al., 2023).
- **The cloud smart strategy:** In 2018, the US government launched the Cloud Smart Strategy, which provides a framework for federal agencies to adopt cloud computing in a secure and sustainable manner. The strategy emphasizes the importance of considering sustainability and energy efficiency in the design and operation of cloud computing systems (Goswami, 2022).
- **The office of federal sustainability:** The Office of Federal Sustainability, established in 2019, coordinates sustainability efforts across federal agencies and promotes the adoption of sustainable practices (Puica, 2020).

So, the US government has recognized the potential of CC to promote sustainable development and has taken steps to promote its adoption in a sustainable and energy-efficient manner.

1.2.2. Europe government policies on sustainable cloud computing

The European Union (EU) has also taken steps to encourage the use of cloud computing in a sustainable manner. The EU has identified cloud computing as a key technology for achieving its sustainability goals, including reducing carbon emissions and promoting resource efficiency (Scott and Watson, 2012). Some of the key initiatives and policies related to cloud computing and sustainable development in the EU include.

- **The EU cloud computing strategy:** The EU CC Strategy, launched in 2012, aims to promote the implementation of CC in Europe and establish a common European market for cloud services (Nesterenko et al., 2020; Li et al., 2022).
- **The European cloud initiative:** The European Cloud Initiative, launched in 2016, aims to promote the development of a European cloud infrastructure for scientific research and innovation. The initiative includes a focus on sustainability and energy efficiency, and encourages the use of energy-efficient technologies and the development of green cloud services (Mentsie et al., 2023; Chandramohan and Ramasamy, 2023).

The EU has recognized the potential of cloud computing to promote sustainable development and has taken steps to promote its adoption in a sustainable and energy-efficient manner. The EU has emphasized the importance of developing energy-efficient data centers, promoting and encouraging the development of sustainable cloud services.

1.2.3. Indian government on cloud computing sustainable development

The Indian government has also taken initiatives to promote the use of CC in a sustainable manner. India has identified CC as a key technology for achieving its sustainability goals, including reducing carbon emissions and promoting resource efficiency (Ciocan and Ivascu, 2014; Dogo et al., 2019). Here are some initiatives and policies launched by Indian government.

- **The national cloud initiative:** The National Cloud Initiative launched in 2013 aims to promote the development of a national cloud infrastructure for public and private sector organizations. The initiative includes a focus on sustainability and energy efficiency and encourages the use of energy-efficient technologies and the development of green cloud services (Nowicka, 2014).
- **The India smart cities mission:** This mission launched in 2015 aims to promote sustainable development in Indian cities. The mission includes a focus on using technology, including CC, to improve efficiency and reduce environmental impacts in urban areas (Alam, 2022).
- **The national green highways mission:** This mission launched in 2015 aims to promote sustainable development in Indian highways. The mission includes a focus on using technology, including cloud computing, to improve efficiency and reduce environmental impacts in highway infrastructure (Wang, 2022).

The Indian government t has recognized the potential of CC to promote sustainable development and has taken steps to promote its adoption in a sustainable and energy-efficient manner (Zhu and Li, 2021).

1.3. Significance of sustainable development in cloud computing

Sustainability in CC can play a significant role in promoting the resource efficiency and simultaneously reducing the environmental impact (Qi, 2021). Here are some ways in which sustainability can be integrated in CC.

- **Energy efficiency:** CC providers can use energy-efficient technologies and practices, such as server virtualization and dynamic resource allocation, to reduce energy consumption and carbon emissions. By consolidating computing resources in data centers and optimizing their use, CC can be more energy-efficient than traditional IT infrastructures (Amendola et al., 2023).
- **Reduced resource consumption:** By using shared resources and avoiding overprovisioning, CC can reduce the depletion of physical resources such as hardware, software, and office space. This can lead to significant cost savings and environmental benefits (Goswami, 2022).
- **Scalability and flexibility:** CC can help organizations avoid unnecessary resource consumption and reduce waste (Oke, 2021).
- **Remote work and telecommuting:** CC can support remote work and telecommuting, reducing the need for employees to commute to work and thereby reducing transportation-related carbon emissions (Dogo et al., 2019; Goswami, 2020).

CC can contribute to sustainable development by improving resource efficiency, reducing environmental impacts, and enabling sustainable business practices. By adopting cloud computing in a sustainable manner, organizations can decrease their environmental footprint and subsidize to a more ecological future.

1.4. Objectives of this present work

Here are some possible objectives for this present research article on sustainable cloud computing.

- To assess the environmental impact of CC and its potential for promoting sustainable development.
- To evaluate the energy and resource efficiency of CC and its role in reducing carbon emissions and resource consumption.
- To identify the challenges and barriers to adopting CC in a sustainable manner and propose solutions to overcome them.
- To examine the business models and pricing strategies of CC providers and their potential to encourage resource efficiency and reduce waste.
- To investigate the role of CC in supporting sustainable practices such as remote work, telecommuting, and virtual meetings.
- To analyze the impact of CC on data privacy and security and propose strategies to enhance data privacy and security in CC.
- To explore the potential of CC in promoting collaboration and knowledge sharing among individuals and organizations to foster innovation and sustainability.
- To propose a framework for assessing the sustainability of cloud computing solutions and guiding organizations in adopting cloud computing in a sustainable manner.

So, the objectives of a research paper on CC sustainable development would depend on the specific research questions and aims of the study. However, the above objectives can provide a starting point for developing a research proposal and identifying the scope of the study.

2. Literature review

Sustainable CC is a concept that aims to reduce the environmental impact of CC while ensuring that it continues to be a reliable and efficient technology. With the increasing demand for cloud services, there is a need to develop sustainable solutions that reduce the energy consumption and carbon footprint of data centers. In this literature review, we explore the existing state of sustainable CC and discuss the challenges and occasions for future research. One of the key encounters in sustainable CC is reducing the energy consumption of data centers (Maksimovic, 2018). To address this challenge, researchers have proposed various solutions, including energy-efficient hardware design, virtualization, and load balancing algorithms. Energy-efficient hardware design involves developing processors and servers that consume less power while maintaining the same level of performance. This approach has been widely adopted by major cloud providers, who have developed custom hardware for their data centers (Sineviciene, 2021). Virtualization is another approach that involves running several simulated apparatuses on a single physical server, thereby reducing the number of servers essential to run applications (Stock et al., 2018). Load balancing algorithms aim to distribute workloads across multiple servers to ensure that none

of the servers are overburdened, thereby reducing energy consumption (Nesterenko et al., 2020). The use of renewable energy sources has been proposed as a solution to this challenge (Mentsie et al., 2023). Additionally, the use of energy storage structures, such as batteries and flywheels, can help reduce the reliance on grid power during peak periods (Puica, 2020). Another approach that has been proposed to promote sustainability in CC is the adoption of circular economy principles. This involves reusing and recycling IT equipment and components to reduce waste and environmental impact. By extending the lifespan of IT equipment, circular economy principles can help reduce the need for new equipment and promote more sustainable consumption patterns (Peñalvo et al., 2022; Ion & Gheorghe, 2014). Finally, there is a need for increased awareness and education about sustainable CC. This includes educating end-users about how to reduce their energy consumption and carbon footprint when using cloud services, as well as training IT professionals in sustainable data center management practices (Jia and Wu, 2022). By adopting a holistic approach that combines energy-efficient hardware design, renewable energy sources, circular economy principles, and edge computing, we can develop more sustainable and resilient CC systems that meet the growing demand for cloud services while reducing their environmental impact.

2.1. Past literatures on sustainable cloud computing

Sustainable CC has expanded in recent years due to its potential to reduce the environmental impact of data centers. CC contribute highly to greenhouse gas emissions, and it is estimated that data centers will consume 8% of global electricity by 2030 (Popović, 2020). Therefore, developing sustainable solutions for cloud computing is critical for mitigating the environmental impact of this technology. Several approaches have been proposed to address this challenge, including energy-efficient hardware design, server virtualization, and load balancing algorithms. Energy-efficient hardware design involves developing processors and servers that consume less power while maintaining the same level of performance. This approach has been widely adopted by major cloud providers, who have developed custom hardware for their data centers (Chou & Chou, 2011; Goswami & Behera, 2021b).

Server virtualization is another approach that involves running multiple applications to ensure that none of the servers are overburdened, thereby reducing energy consumption (Ciocan & Ivascu, 2014). In recent years, many cloud providers have invested in renewable energy sources to control their data centers (Zhu & Li, 2021). Additionally, the use of energy storage systems can help reduce the reliance on grid power during peak periods (Ion and Gheorghe, 2014). Moreover, the circular economy principles can also contribute to promoting sustainability in cloud computing environment. This involves reusing and recycling IT equipment and components to reduce waste and environmental impact. By extending the lifespan of IT equipment, circular economy principles can help reduce the need for new equipment and promote more sustainable consumption patterns (Maksimovic, 2018).

Maksimovic (2018) proposed a dynamic workload consolidation algorithm to consolidate workloads in data centers to minimize energy consumption. The authors compared their proposed algorithm with three existing algorithms and found that their algorithm was more effective in reducing energy consumption. In addition to technical solutions, policy and regulatory frameworks can also play a role in promoting sustainable CC. Governments can set energy efficiency standards for data centers, provide incentives for cloud providers to invest in renewable energy sources, and encourage the adoption of circular economy principles. The European Union, for example, has set a target of 20% reduction in energy consumption by 2020. (Goswami, 2022).

2.2. Previous works on sustainable cloud computing economy

Sustainable CC economy is an emerging concept that focuses on promoting sustainability by reducing waste and promoting circular economy principles. Primary key issues in sustainable CC economy is reducing waste and promoting circular economy principles. This involves reusing and recycling IT equipment and components to reduce waste and environmental impact. By extending the lifespan of IT equipment, circular economy principles can help reduce the need for new equipment and promote more sustainable consumption patterns. The adoption of circular economy principles in CC can also help reduce the reliance on scarce and costly resources, such as rare earth metals used in the production of electronic components (Baliga, 2010). Moreover, sustainable CC economy can also promote the development of new business models that prioritize sustainability. These business models can include pay-per-use and sharing economy models, which aim to reduce the overall consumption of IT resources while promoting more sustainable consumption patterns (Bharany et al., 2022). The sharing economy model, for example, involves sharing IT resources among multiple users, thereby reducing the need for individual users to own and operate their own IT equipment. This model can help reduce the environmental impact of CC by reducing the overall consumption of IT resources (Jing et al., 2013). In addition to promoting circular economy principles and new business models, sustainable CC economy also requires the development of new technologies that enable more sustainable CC. These technologies can include energy-efficient hardware design, server virtualization, and load balancing algorithms (Ciocan and Ivascu, 2014; Stock et al., 2018; Amendola et al., 2023). In conclusion, sustainable CC economy is an emerging concept that aims to promote sustainability by reducing waste, promoting circular economy principles, and developing new business models and technologies. While significant progress has been made in developing sustainable solutions, there is still much work to be done to address the challenges associated with promoting sustainability in CC.

Future research should focus on developing new technologies, business models, and policies that further promote sustainable CC. However, every organization is quite concerned about the sustainable issues related to their firms. Advanced computing technologies is being introduced and installed to achieve the green concept. This will help businesses to grow in wider and also helps to retain the ecological balance within the business environment.

Another challenge in promoting sustainable CC economy is addressing the issue of E-waste. CC relies heavily on electronic devices, and as a result, contributes to e-waste generation. To address this challenge, sustainable CC economy should focus on promoting sustainable e-waste management practices, such as responsible recycling and refurbishing of electronic devices (Chandramohan & Ramasamy, 2023). Some cloud providers, such as Google and Amazon, have already made significant investments in renewable energy sources to control their data centers (Sahoo & Choudhury, 2022). Finally, sustainable CC economy also requires the development of policies and regulations that promote sustainability. Governments promote sustainability by locating energy efficiency standards for data centers, providing incentives for cloud providers to invest in renewable energy sources, and promoting circular economy principles. The EU aims to promote a circular economy across all sectors, including the ICT sector, to reduce waste and promote sustainability (Dougherty et al., 2012).

2.3. Prior research on sustainable cloud computing social benefits

Sustainable cloud computing can provide a range of social benefits, particularly in developing countries. CC can provide access to advanced technologies and services that may not be available locally, such as software applications, data storage, and analytics tools (Chou & Chou, 2011). This can help bridge the digital divide and promote digital inclusion, particularly for individuals and communities with limited access to technology and resources. By leveraging CC technologies, SMEs can access advanced computing resources and services that would otherwise be cost-prohibitive. This can help promote entrepreneurship and innovation, particularly in developing countries where access to resources and funding may be limited (Alam, 2022). Moreover, sustainable CC can also promote social and environmental sustainability. By reducing the need for physical infrastructure and promoting more efficient resource utilization, CC can help reduce the environmental impact of IT services (Park et al., 2023). Finally, sustainable CC can also promote social equity and inclusiveness. By providing access to advanced technologies and services, CC can help level the playing field for individuals and communities that may not have access to these resources. This can help promote social and economic mobility, particularly for individuals and communities that have historically been marginalized or excluded from the benefits of technology.

In addition to the social benefits mentioned above, sustainable CC can also promote social and economic development by improving access to education and healthcare. This can help improve access to education, particularly in developing countries where access to education may be limited (Li et al., 2022). Moreover, CC can also support the development of telemedicine and e-health services, which can help improve access to healthcare, particularly in rural and remote areas. By leveraging CC technologies, healthcare providers can share medical data and expertise across geographic boundaries, improving the quality and efficiency of healthcare services (Scott & Watson, 2012). Finally, sustainable CC can also promote social responsibility and ethical practices. By promoting sustainable consumption patterns, CC can help promote social responsibility and ethical practices in the IT industry (Lee & Zomaya, 2012). This can help create a more sustainable and equitable society, particularly in the context of the growing role of technology in our daily lives (Jing et al., 2013). Sustainable CC can offer a range of social aids, including improving access to education and healthcare, promoting social and economic development, and promoting social responsibility and ethical practices. Future research should focus on developing sustainable CC solutions that maximize these social benefits.

3. Sources of Sustainable Cloud Computing

As the use of cloud computing continues to grow, concerns about its environmental impact have become increasingly important. CC requires significant amounts of energy to power and cool the servers that store and process data, leading to a significant carbon footprint. To address this, cloud providers have been exploring sources of sustainable CC that can reduce their energy consumption and promote sustainability. Additionally, energy-efficient hardware, virtualization, server consolidation, and energy management systems can also help in reduction of energy consumption and improve effectiveness (Li et al.., 2012). Furthermore, cloud providers can adopt sustainable practices, such as using video conferencing instead of traveling, and carbon offsetting to offset their carbon emissions. In this context, it is important to understand the sources of sustainable CC and how they can be leveraged to promote sustainability in the cloud computing industry. There are several sources of sustainable CC, including.

- **Renewable energy sources:** Cloud providers can source renewable energy from solar, wind, hydro, or geothermal power to power their data centers. This can help reduce their carbon footprint and promote sustainability (Wang, 2022).
- **Energy-efficient hardware:** Cloud providers can use energy-efficient servers, storage systems, and networking equipment to decrease energy ingestion and progress efficacy (Dougherty et al., 2012; Zhu and Li, 2021).

- **Energy management systems:** It helps cloud providers monitor and manage their energy usage, enabling them to identify areas where energy can be saved and reduce waste (Li et al., 2022; Popović, 2020).
- **Sustainable practices:** Cloud providers can adopt sustainable practices, such as using video conferencing instead of traveling, using energy-efficient devices, and encouraging customers to adopt sustainable practices (Jia and Wu, 2022; Nara et al., 2021).

Promoting sustainable CC requires a combination of energy-efficient hardware, renewable energy sources, virtualization, server consolidation, energy management systems, sustainable practices, and carbon offsetting. By adopting these practices, cloud providers can reduce their environmental impact and promote sustainability.

4. Potential Threats Caused by Sustainable Cloud Computing

While sustainable cloud computing offers significant benefits for the environment and can help reduce energy consumption, there are also potential threats associated with it. Some of these threats include.

- **Dependence on renewable energy sources:** It can create dependence on the sources if there is a shortage or interruption in the availability of renewable energy, it can affect the availability and performance of cloud services (Zhu and Li, 2021; Dougherty et al., 2012).
- **Data privacy and security:** As cloud providers move towards more sustainable practices, such as server consolidation, there may be an increased risk of data breaches or cyber-attacks. Consolidating data onto fewer servers means that a single breach could potentially expose more data (Lee and Zomaya, 2012).
- **Environmental risks:** While renewable energy sources are generally seen as more environmentally friendly, they can also pose environmental risks. For example, hydroelectric power can impact fish populations, and wind turbines can harm birds and bats (Chandramohan and Ramasamy, 2023).
- **Green washing**: Some cloud providers may claim to be sustainable without actually implementing sustainable practices. This can mislead customers and contribute to a lack of trust in sustainable cloud computing (Markovic et al., 2013).
- **Resource depletion:** While renewable energy sources are more sustainable than non-renewable sources, they still require natural resources such as land, water, and minerals. Overuse of these resources can lead to depletion and environmental damage (Amendola et al., 2023; Bharany et al., 2022).
- **Ethical concerns:** Some renewable energy sources, such as hydroelectric power, can have negative social and ethical impacts. For example, large-scale hydroelectric projects can displace communities and impact indigenous rights (Zhu and Li, 2021).
- **Impact on local economies:** The shift towards sustainable cloud computing can impact local economies, particularly those that rely on traditional energy sources. For example, a decrease in demand for coal can impact coal-mining communities (Park et al., 2023).
- **Complexity and cost:** Implementing sustainable cloud computing practices can be complex and costly. It may require significant investment in new technology, infrastructure, and training, which can be a barrier for some cloud providers (Baliga, 2010).

While sustainable CC offers significant benefits, it also offers some potential threats. By addressing these threats, the cloud computing industry can promote sustainability while minimizing negative impacts on the environment and society.

5. Step Wise Solution to Mitigate the Risk of Cloud Computing

There are solutions that can help promote sustainable CC, which can help reduce energy consumption, lower costs, and mitigate the impact of carbon emissions on the environment (Dougherty et al., 2012; Zhu & Li, 2021). The solutions to the risk of CC include adopting energy-efficient hardware, virtualization and server consolidation, using renewable energy sources, implementing energy management systems, carbon offsetting, promoting sustainable practices, adopting a circular economy approach, collaborating with stakeholders, and investing in research and development (Berl et al., 2010). By implementing these solutions, cloud providers can reduce their environmental impact, promote sustainability, and contribute to a more sustainable future. Here is a step-wise solution for promoting sustainable CC.

- **Conduct an energy audit:** The first step to promoting sustainable CC is to conduct an energy audit of your data center. This can help to identify the areas of setting energy-saving goals (Oliveira et al., 2014).
- **Adopt energy-efficient hardware:** It is important to choose hardware that is designed to consume less energy and operate at high efficiency (Lee & Zomaya, 2012; Baliga, 2010).

- **Utilize renewable energy sources:** Cloud providers can source renewable energy from wind, solar, hydro, and geothermal sources to power their data centers. This can help reduce carbon emissions and promote sustainability (Dougherty et al., 2012; Zhu and Li, 202).
- **Use energy management systems:** Energy management systems can help optimize energy consumption and reduce energy waste. These systems can monitor energy usage, identify energy inefficiencies, and automate energy-saving actions (Park et al., 2023; Jing et al., 2013).
- **Promote sustainable practices:** Cloud providers can promote sustainable practices such as video conferencing instead of traveling, reducing paper usage, and promoting telecommuting (Zhu and Li, 2021).
- **Monitor and report sustainability metrics:** It is important to monitor and report sustainability metrics to track progress towards sustainability goals and ensure transparency with customers (Goswami, 2022).
- **Continuously improve sustainability practices:** Sustainable CC requires continuous improvement and adaptation to new technologies and practices. Cloud providers should regularly evaluate their sustainability practices and look for ways to improve efficiency and reduce environmental impact (Zhu and Li, 2021).
- **Develop a sustainability strategy:** Developing a comprehensive sustainability strategy can help guide sustainable CC practices and ensure alignment with corporate goals. The strategy should include goals, metrics, and timelines for reducing carbon emissions and promoting sustainability (Lee and Zomaya, 2012; Baek et al., 2014).
- **Encourage customers to adopt sustainable practices:** Cloud providers can uphold energy-efficient services, promoting virtual meetings and remote work, and incentivizing sustainable behavior (Popović, 2020).
- **Implement a circular economy:** A circular economy approach involves reducing waste, promoting reuse and recycling, and recovering resources. Cloud providers can implement a circular economy approach by repurposing or recycling hardware, using sustainable materials, and reducing waste (Oliveira et al., 2014).
- **Collaborate with stakeholders:** Collaboration with stakeholders such as suppliers, customers, and government agencies can help promote sustainable CC practices. This can involve sharing best practices, collaborating on sustainability initiatives, and advocating for policy changes that promote sustainability (Bag and Pretorius, 2022).
- **Invest in research and development:** It helps to promote sustainable CC by developing new technologies and practices that are more energy-efficient, sustainable, and cost-effective (Baek et al., 2014).

Promoting sustainable CC requires a comprehensive approach that involves energy efficiency, renewable energy sources, carbon offsetting, and sustainable practices.

6. Role of Sustainability in Promoting Sustainable Cloud Computing

Sustainability plays a crucial role in promoting sustainable CC (Yu et al., 2022). Here are some ways in which sustainability can promote sustainable cloud computing.

6.1. Reducing energy consumption

Reducing energy consumption is a critical aspect of promoting sustainable CC. Here are some ways to promote energy efficiency in CC.

- **Use energy-efficient hardware:** Cloud providers can select hardware that meets Energy Star standards and Energy Efficiency Rating (EER) to reduce energy consumption (Bag & Pretorius, 2022; Berl et al., 2010).
- **Implement energy management systems:** Energy management systems (EMS) can help optimize energy usage in data centers. These systems can monitor energy usage, control and automate power distribution, and optimize cooling systems to reduce energy consumption (Lee & Zomaya, 2012).
- **Adopt intelligent workload management:** Intelligent workload management involves dynamically allocating computing resources based on application workload. This can help reduce energy consumption by optimizing resource usage (Walterbusch et al., 2015; Chou & Chou, 2011).
- **Use renewable energy sources:** Cloud providers can source renewable energy from wind, solar, hydro, and geothermal sources to power data centers. This can significantly reduce carbon emissions and promote sustainability (Bressanelli et al., 2022; Valentini et al., 2013).

Reducing energy consumption is essential for promoting sustainable CC (Bag & Pretorius, 2022). By using energy-efficient hardware, adopting virtualization and server consolidation, implementing energy management systems, using free cooling techniques, adopting intelligent workload management, using renewable energy sources, and implementing PUE monitoring, cloud providers can significantly reduce their energy consumption, and promote sustainability.

6.2. Carbon offsetting

Carbon offsetting can be a useful tool to help reduce the carbon footprint of CC (Bressanelli et al., 2022). Here are some ways to promote carbon offsetting for sustainable CC.

- **Educate users about carbon offsetting:** Many users may not be aware of the concept of carbon offsetting and its benefits. Therefore, it is essential to educate users about the importance of carbon offsetting and how it can help reduce the carbon footprint of CC (Nara et al., 2021).
- **Provide information about the carbon footprint of cloud computing:** Users should be informed about the carbon emissions associated with CC. This information can help them understand the importance of carbon offsetting and the impact it can have on the environment (Duan., 2020).
- **Offer carbon offsetting options:** Cloud service providers can offer carbon offsetting options to their customers. This can be in the form of a carbon offsetting program that allows customers to purchase carbon credits to offset the carbon emissions generated by their cloud usage (Oliveira et al., 2014).
- **Integrate carbon offsetting into cloud computing platforms:** CC platforms can integrate carbon offsetting into their services. For example, they can offer a carbon calculator that allows users to calculate their carbon footprint and offer carbon offsetting options based on the results (Valentini et al., 2013; Berl et al., 2010; Park et al., 2023).
- **Collaborate with carbon offsetting organizations:** Cloud service providers can collaborate with carbon offsetting organizations to promote carbon offsetting. By working together, they can raise awareness about the importance of carbon offsetting and make it easier for customers to offset their carbon footprint (Bressanelli et al., 2022; Walterbusch et al., 2015).
- **Set targets for carbon reduction:** Cloud service providers can set targets for carbon reduction and track their progress (Bag & Pretorius, 2022; Baliga, 2010).

Promoting carbon offsetting for sustainable CC requires a combination of education, awareness, and action. By working together, we can reduce the carbon footprint of CC and create a more sustainable future.

6.3. Adopting a circular economy approach

A circular economy approach involves reducing waste, promoting reuse and recycling, and recovering resources. Cloud providers can implement a circular economy approach by repurposing or recycling hardware, using sustainable materials, and reducing waste (Park et al., 2023). Adopting a circular economy approach for sustainable cloud computing can involve several strategies, some of which are outlined below.

- **Design for circularity:** CC systems should be designed with circularity in mind, which means designing for longevity, recyclability, and reparability. This could involve using modular designs, using materials that are easily recyclable, and ensuring that systems can be repaired easily (Valentini et al., 2013).
- **Encourage sustainable consumption:** Adopting a circular economy approach also involves promoting sustainable consumption patterns, which can involve encouraging users to use CC resources efficiently and to minimize waste (Ferrer et al., 2012; Bayramusta & Nasir, 2016).
- **Develop sustainable supply chains:** To promote circularity in sustainable supply chains that can involve working with suppliers to reduce waste and improve recycling practices (Duan., 2020).
- **Emphasize the benefits of circular economy:** Finally, promoting a circular economy approach for CC involves emphasizing the benefits of this approach, including reduced environmental impact, improved resource efficiency, and increased resilience to supply chain disruptions (Chandramohan & Ramasamy, 2023).

Therefore, promoting a circular economy approach for sustainable CC involves a combination of technological, policy, and behavioral interventions, as well as collaboration between stakeholders across the CC value chain.

6.4. Collaboration with stakeholders

Collaboration with stakeholders such as suppliers, customers, and government agencies can help promote sustainable cloud computing practices (Awan et al., 2021). This can involve sharing best practices, collaborating on sustainability initiatives, and advocating for policy changes that promote sustainability. Promoting collaboration with stakeholders is crucial to achieving sustainable CC. Some strategies to foster collaboration include.

- **Engage stakeholders in the development process:** Engage stakeholders such as customers, suppliers, policymakers, and NGOs in the development of sustainable CC policies and strategies. This can involve hosting workshops, roundtables, and other events to solicit feedback and input from stakeholders (Ferrer et al., 2012; Chou and Chou, 2011).

- **Share knowledge and best practices:** Share knowledge and best practices with stakeholders to promote sustainable CC. This can involve providing training and educational resources, sharing case studies and success stories, and disseminating research and data on sustainable CC (Di Salvo et al., 2017; Zhu and Li, 2021).
- **Align incentives:** Align incentives for stakeholders to promote sustainable CC. This can involve offering financial incentives, such as tax credits or rebates, to companies that adopt sustainable practices, or setting performance targets and rewarding those who achieve them (Chou and Chou, 2011; Valentini et al., 2013).
- **Monitor and evaluate progress:** Regularly monitor and evaluate progress toward sustainable CC goals, and report on successes and challenges. This can involve setting metrics and benchmarks to track progress, and soliciting feedback from stakeholders on what is working and what needs improvement (Awan et al., 2021; Dougherty et al., 2012).

By promoting collaboration with stakeholders, sustainable CC can be achieved through shared efforts and collective action towards common goals.

6.5. Investing in research and development

Investing in research and development can help identify new and innovative ways to reduce the environmental impact of CC. This can involve developing new technologies, improving efficiency, and optimizing data center operations (Walterbusch et al., 2015). Investing in research and development for sustainable CC is crucial to advancing in the field of sustainability. Some strategies to promote such investments include.

- **Private sector investment:** This can involve allocating resources to internal research and development teams, or investing in startups and other emerging companies that are developing sustainable CC solutions (Bag & Pretorius, 2022).
- **Collaborative research:** Foster collaborative research efforts between industry, academia, and other stakeholders to identify new solutions for sustainable CC. This can involve forming research partnerships, hosting workshops and conferences, and promoting knowledge-sharing across different sectors (Bayramusta & Nasir, 2016; Valentini et al., 2013).
- **Incentivizing innovation:** Provide incentives for innovation in sustainable CC. This can involve offering monetary incentives for companies that develop new sustainable technologies, or creating awards and recognition programs to encourage innovation (Hamdaqa & Tahvildari, 2012).
- **Open-source software development:** Promote the development of open-source software solutions for sustainable CC. This can involve contributing to open-source projects or initiating new projects that are focused on developing sustainable cloud computing technologies (Hamdaqa & Tahvildari, 2012).

6.6. Implementing green building practices

Green building practices such as designing energy-efficient data centers, using sustainable building materials, and implementing green infrastructure can significantly reduce the environmental impact of cloud computing. Implementing green building practices is crucial to achieving sustainable CC as data centers are significant energy users (Hamdaqa & Tahvildari, 2012). Here are some strategies to implement green building practices for sustainable CC.

- **Energy-efficient design:** Adopt energy-efficient building design practices to reduce energy consumption, such as using passive cooling, optimizing the building's orientation and using building envelope systems that reduce the cooling needs (Valentini et al., 2013; (Di Salvo et al., 2017)).
- **Efficient cooling systems:** Optimize the cooling systems by using air-side economizers or liquid cooling, using high-efficiency HVAC systems, or applying hot and cold aisle containment methods (Park et al., 2023; (Baek et al., 2014)).
- **Efficient power usage:** Optimize power usage by using energy-efficient lighting and using smart building systems to control and reduce energy usage in unused or low-demand areas (Hamdaqa & Tahvildari, 2012).
- **Sustainable materials:** Use sustainable materials in the building construction, such as using recycled materials or materials with a lower carbon footprint (Park et al., 2023; Bayramusta & Nasir, 2016).
- **Green landscaping:** Incorporate green landscaping practices such as native plants that require minimal water and maintenance, and design landscapes to naturally cool the surrounding areas (Bayramusta & Nasir, 2016; Park et al., 2023).
- **Regular monitoring and reporting:** Regularly monitor energy and water consumption, and report on progress towards sustainable building practices to stakeholders (Park et al., 2023).

Implementing green building practices for sustainable CC requires a commitment to the environment and a willingness to invest in sustainable solutions (Basmadjian, 2019). By adopting these practices, we can reduce energy consumption and minimize the environmental impact of data centers, thus achieving sustainable CC.

6.7. Educating employees and customers

This can involve training employees on sustainability practices, promoting sustainable behavior, and communicating the organization's sustainability goals and initiatives to customers. Educating employees and customers is an essential aspect of promoting sustainable CC (Hamdaqa & Tahvildari, 2012; Bressanelli et al., 2022). Here are some strategies to effectively educate employees and customers on sustainable CC.

- **Internal training programs:** Conduct internal training programs for employees to increase awareness and promote sustainable practices. This can involve providing information on energy-efficient computing practices, promoting the use of green IT hardware, and encouraging employees to adopt sustainable behaviors (Ferrer et al., 2012; Di Salvo et al., 2017).
- **Customer education:** This can include providing tips for reducing energy consumption, using efficient computing practices, and selecting cloud providers who prioritize sustainability (Ferrer et al., 2012).
- **Promote sustainable behavior:** Encourage employees and customers to adopt sustainable behavior by promoting the use of teleconferencing instead of travel, reducing paper usage, recycling, and reducing energy consumption (Duan., 2020; Di Salvo et al., 2017; Baek et al., 2014).
- **Collaborate with partners:** Collaborate with partners in the CC industry to create joint educational programs and resources that promote sustainable practices (Zhu & Li, 2021).
- **Measure and report progress:** Monitor and report progress towards sustainable CC goals to stakeholders. This can include measuring energy consumption, reducing greenhouse gas emissions, and implementing sustainable practices (Bharany et al., 2022).

By educating employees and customers on sustainable CC, we can create a culture of sustainability that leads to more efficient and environmentally responsible CC practices.

6.8. Incorporating sustainability into business strategy

Incorporating sustainability into the organization's business strategy can help promote sustainable CC practices. This can involve setting sustainability goals, measuring and reporting on sustainability performance, and integrating sustainability considerations into decision-making processes (Yu et al., 2022). Incorporating sustainability into the business strategy is crucial to achieving sustainable CC. Here are some strategies to effectively incorporate sustainability into business strategy for sustainable CC.

- **Set sustainability goals:** Set clear sustainability goals and targets that are integrated into the overall business strategy. This can involve establishing sustainability performance metrics, tracking progress, and reporting on results to stakeholders (Carcary et al., 2014).
- **Conduct a sustainability assessment:** Conduct a sustainability assessment of the organization's CC operations to identify areas where sustainability can be improved. This can involve analyzing energy consumption, greenhouse gas emissions, and other environmental impacts (Nara et al., 2021).
- **Adopt sustainable practices:** Implement sustainable practices that reduce environmental impact and improve operational efficiency. This can include optimizing server utilization, adopting energy-efficient hardware, and implementing virtualization and cloud-based computing technologies (Chou, 2015).
- **Collaborate with suppliers:** Collaborate with suppliers to ensure that they are adopting sustainable practices. This can involve setting sustainability standards for suppliers, monitoring compliance, and working with them to improve their sustainability practices (Yu et al., 2022).
- **Engage stakeholders:** Engage stakeholders such as customers, employees, investors, and regulatory bodies to promote sustainable practices and to demonstrate the organization's commitment to sustainability (Yu et al., 2022).
- **Establish a sustainability team:** Establish a sustainability team to oversee sustainability initiatives and to ensure that sustainability is integrated into all business functions (Bharany et al., 2022).
- **Continuously improve:** Continuously evaluate and improve sustainability performance by conducting regular assessments, setting new goals, and implementing new initiatives to improve sustainability practices (Carcary et al., 2014).

By incorporating sustainability into the business strategy for CC, organizations can reduce environmental impact and simultaneously improve operational efficiency (Hamdaqa & Tahvildari, 2012). Hence, sustainability plays a crucial role in promoting sustainable CC. By adopting sustainable practices, implementing green building practices, educating employees and customers, and incorporating sustainability into business strategy, cloud providers can significantly reduce their ecological impact and promote sustainability.

7. Conclusion

Sustainable CC is an essential aspect of creating a more sustainable future. CC is becoming increasingly prevalent in today's digital world, and its environmental impact cannot be ignored. Therefore, it is necessary to promote sustainable practices in CC to minimize its negative impact on the environment. The strategies to achieve sustainable CC involve implementing energy-efficient designs, using renewable energy, optimizing cooling systems, using sustainable materials, conserving water, and promoting green landscaping. Additionally, educating employees and customers, collaborating with stakeholders, investing in research and development, and incorporating sustainability into business strategy can significantly contribute to achieving sustainable CC. It offers various benefits such as reduced energy consumption, lower costs, improved efficiency, and enhanced reputation. Moreover, it enables organizations to meet their sustainability goals, comply with regulations, and fulfill their social responsibilities. As such, it is crucial for organizations to make a conscious effort towards achieving sustainable cloud computing by adopting the practices discussed above. Furthermore, sustainable CC is not only a responsibility of organizations but also of individuals. Individuals can play their part in promoting sustainable CC by adopting sustainable behaviors such as reducing energy consumption, using energy-efficient devices, and choosing cloud providers who prioritize sustainability. This can contribute to reducing the overall environmental impact of CC. It is worth noting that sustainable CC is a rapidly evolving field, and new technologies and practices are emerging continuously. As such, organizations and individuals must keep up-to-date with the latest developments and continue to innovate and improve their sustainability practices continually. Finally, achieving sustainable CC requires a collaborative effort from all stakeholders, including government bodies, non-governmental organizations, the private sector, and individuals. By working together, we can create a more sustainable and resilient future, where CC can continue to play a critical role in supporting our digital economy and improving our quality of life.

7.1. Practical implications

Sustainable CC has several practical implications that organizations, individuals, and society at large should consider. Here are some practical implications of sustainable CC.

- **Cost savings:** Sustainable CC can result in cost savings for organizations. Energy-efficient practices, efficient hardware, and optimized server utilization can reduce energy consumption and operational costs. These cost savings can be reinvested in research and development or used to fund sustainability initiatives.
- **Reputation:** Sustainable CC can enhance an organization’s reputation by demonstrating its commitment to sustainability and social responsibility. Customers and investors are increasingly seeking environmentally conscious companies to do business with, and promoting sustainable practices can help organizations stand out in the marketplace.
- **Compliance:** Sustainable CC can help organizations comply with environmental regulations and standards. As environmental regulations become more stringent, companies must adopt sustainable practices to avoid penalties, fines, and other legal issues.
- **Innovation:** Sustainable CC can drive innovation by promoting the practices that reduces environmental impact. This innovation can lead to new business opportunities, increased efficiency, and reduced costs.
- **Collaboration:** Sustainable CC requires collaboration among stakeholders, including government, private sector, NGOs, and individuals. By working together, stakeholders can develop best practices and promote sustainability initiatives.
- **Education:** Sustainable CC requires educating employees and customers on sustainable practices. By creating a culture of sustainability, organizations can promote sustainable behaviors and reduce their environmental impact. Educating customers on sustainable practices can also encourage them to adopt sustainable behaviors, contributing to a more sustainable future.
- **Research and development:** Sustainable CC requires investment in research and development. This investment can lead to new innovations, increased efficiency, and reduced costs over time.

By considering these practical implications, organizations and individuals can adopt sustainable practices that reduce the environmental impact of CC and promote sustainability. By doing so, they can reduce costs, enhance their reputation, comply with regulations, drive innovation, promote collaboration and education, and contribute to creating a more sustainable future.

7.2. Limitation

Despite its many advantages, cloud computing is not without its constraints for sustainable development. Here are a few examples of some of the obstacles to achieving the right kind of sustainable development.

- **Limited scope:** A research paper on sustainable CC may have a limited scope, focusing only on certain aspects of sustainability or certain types of CC technologies. This can restrict the generalizability of the study findings and may not provide a comprehensive understanding of sustainable CC as a whole.
- **Bias and confounding factors:** Research studies on sustainable CC may be subject to bias and confounding factors, such as the influence of funding sources or the effect of external factors that are not accounted for in the study design. This can limit the legitimacy and trustworthiness of the study findings.

By discussing these limitations in a research paper, researchers can provide a more comprehensive understanding of the challenges and limitations of sustainable CC research. Additionally, identifying these limitations can help to guide future research in sustainable CC and promote the development of more robust and standardized methodologies for studying the environmental impact of CC.

7.3. Future Scope

There are numerous places where we might concentrate our efforts in the future work of sustainable development in CC that are follows.

- **Adoption of circular economy principles:** The circular economy emphasizes the reuse, refurbishment, and recycling of resources to minimize waste and promote sustainability. Future research can focus on the adoption of circular economy principles in cloud computing, such as the reuse of old servers and other hardware components.
- **Education and awareness:** Educating employees and customers on sustainable practices is a critical component of sustainable CC. Future research can focus on developing and implementing effective education and awareness programs to promote sustainable behaviors and practices.

Researchers might find prospective areas of concentration for future research in sustainable CC by outlining these future scopes in a research article. Additionally, by promoting sustainability throughout the IT sector, these future scopes can assist organizations in adopting sustainable CC practices.

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Conflict of Interest

The author(s) declare that there are no conflicts of interest to disclose.

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