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TITLE: REVIEW OF CLOUD COMPUTING IMPACT ON SUSTAINABLE DEVELOPMENT

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Review of cloud computing impact on sustainable development

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***Abstract*—The adoption rate of cloud computing is on the rise due to the beneficial features of cloud that facilitated organizations in the issue of procuring computing resources. The high adoption rate would translate to increasing demand of data centers to be built, where data centers are heavy consumer of power and water for their daily operations. This introduces the concern of environmental impact from the data centers. The current condition of the environment is deteriorating thus require immediate actions to be taken to reverse the damages done. Sustainable development has been an important initiative by the United Nations to promote the consideration of sustainability into actions and decisions to ensure future sustainability. This study reviews the potential impact of cloud computing has towards environmental sustainability. In addition, assessing how cloud service providers are performing their role in achieving sustainable development. Cloud service providers are committed to the environmental sustainability movement and have implemented various initiatives to increase resource utilization to minimize impacts towards the environment. However, at the granular level, better awareness for cloud consumers of their choices and actions is encouraged, to further improve the effectiveness of achieving sustainable development.**

Keywords—Sustainable development, Cloud computing, Service, Deployment

I. Introduction

The environment is depleting, resulting from the decades of unsustainable economic decisions and activities. This resulted in a severely disrupted natural system which has affected every single creature on earth. It is evident that the earth is experiencing an acceleration in global warming that is leading to mass extinction of species, food security risks, unusual weather, etc. The most effective way to reverse the damages is to significantly reduce the emission of greenhouse gasses as soon as possible [1].

Considering the severe effects from global warming that may affect the livelihood of all species, the United Nations has developed a framework for all nations to participate and adopt to collectively combat climate change. On top of achieving sustainability in the environment, the framework addresses the societal and economic aspects with hope to achieve a balance between them. The goal of the framework is to develop a healthy, fair, and sustainable future environment for the better livelihood of all people.

With the increasing rate of digital transformation, organizations are increasingly adopting cloud solutions by hosting applications and data to the cloud. This has transformed the working paradigm, allowing organizations to utilize computing platforms, software, applications, and services via the internet by any devices. This has reduced the reliance of physical computing infrastructures required in organizations. In addition, in the era of big data where organizations require increasing computation power and storage would reap the benefits of cloud computing by having the flexibility to procure additional computing resources on demand through cloud service providers.

However, organizations adopting the cloud solution does not stop the potential impacts towards the environment. Cloud service providers rely on data centers filled with state-of-the-art computing infrastructures to provide high availability services to consumers. These data centers consume great amount of electricity and water for powering and cooling the facilities while producing emissions that may negatively impact the environment. The increasing demand for cloud services translate to increasing growth of number of data centers around the globe. This results in greater consumption of power and water by the emerging data centers. In addition, disposal of decommissioned machines and obsolete technologies would create another concern for the environment.

This paper reviews the benefits and impacts of cloud computing towards sustainable development. In addition, assessing the green initiatives of several cloud service providers as part of their duty in achieving environmental sustainability.

II. Sustainable Development

Sustainable development refers to the actions taken at present, to meet the current needs of current generations while also taking into considerations the impacts and sustainability for the needs of future generations. The results from decades of economic development without considering future impacts have caused a considerable amount of damage to the environment. As most products we used today derived initially from natural resources, the condition of the environment and natural resources has since been depleting at a rapid and unsustainable rate. Example of consequences from such activities lead to climate change and deteriorating of water and air quality. Therefore, the need for sustainable development is emphasized to ensure the limited natural resources are utilized in a much more efficient and sustainable manner, for the sake of the planet and the future livelihood of humans.

Sustainable development does not only focus on the environmental aspect. But it is the foundation for one of the three core principles of sustainable development as defined by the United Nations. Initiated by the United Nations, a framework with 17 goals was developed to guide the global nations into achieving sustainable development by 2030 [2]. The three pillars of sustainable development which needs to be balanced are the economic, social, and the environmental

aspects. With the environmental aspect being the foundation that supports both the development of the society and the economy. This indicates that achieving environmental sustainability is just the starting point. The goal of sustainable development is to produce a world with more responsible, equitable, and healthier future generations along with sustainable economic growth. One example of sustainable development that is applied in data centers, is the harnessing and using of wind energy in replaced with coal generated energy. Wind energy is a cleaner and renewable energy as compared to coal generated energy. This movement greatly benefits the environment by reducing the release of harmful pollutants into the environment. Thus, creating a healthier and cleaner environment for years to come. Therefore, sustainable development encourages the reconsideration of our current actions, to ensure benefits for the present and future.

The adoption of cloud computing can drive companies to achieving the sustainable development goals. Companies utilizing cloud computing can benefits from reduced capital expenditures while also contributing to achieving sustainable development by reducing the generation of e-waste [3]. Sustainability in information and communication technology is achieved by enhancing product durability and adopting a eco-friendly design [4]. Resource pooling which is a characteristic of cloud computing has allowed the sharing of computing resources, achieving much higher resource utilization rate. This results in an improved efficiency in energy consumption, more efficient usage of resources, and reduced pollutant emissions to the atmosphere. Forecasting done by Accenture, showed that the increasing migration to cloud can potentially see a reduction in the global carbon dioxide emission by 59 million tons per year before the year 2025, which is equivalent to taking off 22 million cars from the road [5].

III. Cloud Computing

Traditionally, companies are required to invest a large initial capital to acquire computing resources. In addition to the acquisition, the companies are required to employ additional staffs to manage and maintain the computing resources, which increases the overall costs. However, with the emergence of cloud computing and the era of big data, companies have started to realize the benefits of cloud and has since consider the adoption of cloud computing as a necessity instead of an option. It has then changed the model of owning computing infrastructures to a subscription-based model of hiring on-demand computing resources from cloud providers.

According to [6], the National Institute of Standards and Technology (NIST) definition of cloud computing is provided as "A model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction. Following the definition, the cloud model comprises of five essential characteristics, three primary service models, and four types of deployment models." In simpler terms, cloud computing refers to the delivery of hardware and software resources over the internet to facilitate better flexibility, greater innovation, and efficient scalability.

The following list the five essential cloud computing characteristics:

A. On-Demand Self-Service

Provisioning of cloud resources which can include processing power, network, storage, and software can be easily performed by cloud consumers using dedicated online portals without the need for human interaction. In addition, flexibility is provided to cloud consumers where the provisioning of cloud resources can be requested at any time. This significantly improves the efficiency in terms of time and effort in provisioning the required computing resources. Which allows companies to reduce the need to invest a huge upfront cost for computing resources that may not reach high utilization rate or experience insufficient computing resources to meet a sudden demand surge that may happen only a few times per year. The on-demand self service allows companies to provision the needed computing resources with just simple interaction with the online interface through a subscription-based model. Thus, provisioning of resources can be done very quickly and would only require paying for what has been utilized. This results in better cost effectiveness achieved for the companies while minimizing waste in resources. Therefore, companies contribute to sustainable development by reducing and improving efficiency of using resources.

B. Broad Network Access

Broad network access refers to the accessibility of cloud services through network on a wide range of devices, which can include thin or thick client platforms. This ensures that cloud resources are not hindered by the different platforms used, thus would provide a continuous workflow process at anywhere using any devices. Example of where this cloud capability can be observed is remote working. Broad network access has provided the opportunity for employees to access company resources and applications online using their own personal devices without the need to step into the office. [7] conducted a study on environmental impact from remote working in Italy. It was found that fully or partially remote working has positively contributed to the sustainability of the environment. The daily commute of employees to offices produces a significant amount of greenhouse gases. The reduction of commuting can reduce the harmful emission to the environment. Therefore, achieving sustainable development by reducing emissions and saving resources by using existing devices to access to company resources.

C. Resource Pooling

Built on top the multi-tenancy model, resource pooling refers to the provision of pooled computing resources by cloud providers to serve multiple cloud consumers by dynamically assigning and reassigning physical and virtual resources depending on consumer demands. The resources may include storage, processing, memory, and network bandwidth. This allows cloud service providers to significantly increase the resource utilization rate due to the flexibility in provisioning and reclaiming resources. One application of resource pooling can be seen when cloud service providers are serving clients from different time zones. Computing resources are efficiently reallocated from clients in the non-active time zones to the clients in the active

time zones, achieving a high utilization rate using the same resources.

D. Rapid Elasticity

Rapid elasticity refers to the ability to dynamically scale cloud resources to adapt to varying workloads on demand of cloud consumers. In the event of a sudden surge in online traffic, additional cloud resources can be automatically provisioned temporarily to cater for the excess demand. This allows cloud consumers to maintain adequate performance levels while only required to pay for the temporary excessive cloud resources utilized. This in turn helps the cloud consumers to save on costs by not having to provision excess resources. This capability provides flexible scaling of cloud resources to meet consumer demand in the event of surging online traffic or to perform testing and development of an application at a greater scale to ensure minimal downtime is expected.

E. Measured Service

Measured service refers to the measuring and monitoring of usage of cloud resources which is transparent for both cloud providers and cloud consumers. This measure is important for assessing the current customer demands to ensure the capacity from cloud service providers are able to meet the Service Level Agreements. In addition, this allows accurate billing of the actual amount of computing resources used while providing information for better planning of capacity and service to meet future demands. Cloud resources are finite, with the increasing adoption of cloud computing, cloud service providers must ensure the capacity and services provided are able to handle the increasing load, ensuring minimum downtime is experienced. The reliance of cloud is increasing, where a downtime would cause major consequences to both cloud consumers and cloud providers.

IV. Cloud Service Models and Deployment Models

Based on NIST specification, cloud computing comprised of three primary cloud service models and four primary cloud deployment models. However, there exists many more cloud service and deployment models which are built on top the primary models. These additional models are deemed as secondary models.

A. Cloud Service Models

Cloud service models specifies the service configuration which can be a combination of different computing resources and capabilities provided by cloud service providers to meet specific business requirements of the consumers. The three primary service models are Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS).

1) Infrastructure as a Service

IaaS provides the flexibility in provisioning cloud infrastructures which typically consist of network, storage, and computing power to end users. This allows end users to reduce the reliance in on-premises infrastructures which reduces capital expenditures and hassle of maintenance. In addition, end users have full control of the infrastructures which provides greater flexibility and scalability to procure additional computing resources on-demand and pay only for what they need and used. IaaS is suitable for companies seeking for computing power to run their workloads but have very limited capital expenditure. Some examples of IaaS providers include AWS EC2, Google Compute Engine, and Microsoft Azure.

2) Platform as a Service

PaaS provides the accessibility to frameworks, software, and tools via the internet where developers can develop applications and software. It allows developers to focus on the application development without the need to worry about the underlying computing infrastructures. In addition, PaaS provides the platform for testing new applications. However, cloud consumers who are selecting this service would need to take into considerations for the compatibility of languages and frameworks provided. As there may exist a difference between the languages and frameworks used by the end user and the cloud service provider. This may lead to lower performance or inhibit operational capabilities. PaaS is suitable for companies that are implementing agile methodologies where new applications can be released quickly and gather user feedbacks in shorter period. Some examples of PaaS providers include AWS Elastic Beanstalk, Windows Azure, and Google App Engine.

3) Software as a Service

SaaS refers to the delivery of software and applications which are available to end users via internet and typically runs on a web browser. End users can directly utilize the services from the software on any web browser without the need to perform any downloading or installation tasks. However, integration between existing applications may be a problem since many SaaS providers do not have the option of open integrations. SaaS platforms are ideal for consumers who require a smooth and reliable usage of the application without the need to worry on maintenance and update of infrastructures. Some examples of SaaS providers include Dropbox, Google Workspace, and Salesforce.

4) Discussion

In the standpoint of sustainable development, each type of service model contributes to environmental sustainability in a different but positive way. In general, the adoption of cloud computing would greatly reduce the need to procure physical infrastructures and office spaces which lead to lower consumption of energy and resources. Cloud infrastructures provided by cloud service providers are typically shared among several users which increases resource utilization rate and are more efficient in energy consumption leading to lower emissions and lesser wastage.

Comparing the responsibility of consumer in procuring computing resources. IaaS requires consumers to procure the greatest number of infrastructures which can lead to wastage and inefficiency if not managed properly. For PaaS, lesser procurement of infrastructures is required as compared to IaaS and can be easily managed while the SaaS require the least infrastructure to be managed. The lesser the infrastructure to be managed by consumers, the closer it is to achieving sustainable development. This is due to most consumers do not have efficient and high utilization rate of the procured infrastructures as compared to a cloud service provider. This led to generating more waste and emissions which reduces environmental sustainability.

Among the three service models, SaaS is the most popular and with the highest adoption rate. This can be due to the increasing ease of hosting applications over the internet and having broad network access to the application services. In the recent Covid-19 pandemic, a shift to remote working and increasing adoption of such model as the new normal has seen the benefits of SaaS. Where employees can continue working from home by accessing cloud hosted company applications. This in turn significantly reduced the requirement to commute which benefited the environment by reducing emissions.

In addition, SaaS can contribute the most to sustainable development as organizations migrated their services to the cloud resulting in lower physical infrastructures requirements. The responsibility of providing cloud infrastructures have shifted to the cloud service providers where dedicated personnel and facilities are implemented to ensure highest efficiency is achieved in resource utilization. Data centers are highly optimized and increasingly adopting renewable energy as their source of cooling and powering the servers. This results in much more efficient usage of computing infrastructures and increases energy efficiency while achieving environmental sustainability.

B. Cloud Deployment Models

Cloud deployment models define the management and accessibility of the cloud environment. It defines the location of the servers and who is holding responsibility to control them. The four primary cloud deployment models are public cloud, private cloud, community cloud, and hybrid cloud.

1) Public Cloud

Public cloud refers to the provisioning of cloud infrastructures from a cloud service provider where the cloud resources are being shared among the public. The cloud service providers hold full responsibility for maintaining and managing the infrastructures. This provides scalability for end users without the need to purchase any hardware which also saved the costs of setting up and maintenance. In addition, computing resources can be procured on-demand and have immediate access to the resources. However, the public cloud may not be suitable for users who are handling sensitive data and critical applications that require highly secured platforms. This is due to the security concerns that may arise due to the public cloud which can be accessed by multiple public users of the same cloud resources.

2) Private Cloud

Private cloud refers to cloud infrastructures that are specifically provisioned to cater for one single organization which can comprise of multiple users under the same organization. The cloud infrastructures will not be shared with other organizations and the organization itself is responsible for maintaining and managing the infrastructures. Such model is called the on-premises private cloud where organization set up its own data center within its premises. It provides a highly secured cloud environment and complete control over the resources which are typically managed by a dedicated team. Another model of private cloud is called the externally hosted private cloud. Where the cloud implementation is outsourced to an external cloud service provider and users would access to the cloud resources via a secured network. Located at the premises of the provider, the cloud infrastructures will be isolated from other tenants and be exclusive to the single organization. Private cloud provides greater flexibility as compared to public cloud in terms of controlling and managing cloud resources. In addition, it provides the highest security and privacy for the data stored in the exclusive cloud environment.

3) Community Cloud

Community cloud refers to the cloud infrastructures that are accessible by only a specific group of organizations typically having a shared concern. It is similar to a private cloud, but accessibility is limited to a specific group of organizations. The cloud infrastructures may be managed by one or multiple organizations within the specified community, outsourced to cloud providers, or a combination of them. Community cloud is much more cost effective as compared to a private cloud since the resources are shared among several organizations thus the billing will also be shared among the organizations. In addition, security is upheld as the cloud is not accessible to the public, but only within the circle of specific organizations. This type of deployment model is suitable for organizations seeking for collaboration on specific domain and data sharing.

4) Hybrid Cloud

Hybrid cloud refers to the combination usage of two or more types of cloud deployment models. The combination usage of a public and private cloud is generally popular. This is due to organizations typically have some computing infrastructures implemented on-premises in the past. As the organization starts to grow, additional computing resources is required which can be facilitated by adopting a public cloud. Another usage of combining public and private cloud is the hosting of critical applications and sensitive data on the private cloud, which is more secured. While migrating the non-critical items to the public cloud which is more cost effective. In addition, hybrid cloud provides the capacity to handle cloud bursting event. Where the provisioning of additional computing resources temporarily can be done from a public cloud to temporarily handle the traffic surge and return to normal capacity once the surge is over.

5) Discussion

Considering the topic of sustainable development, organizations implementing cloud deployment model would need to balance between prioritizing security or improving environmental sustainability. Public cloud being the most environmentally sustainable since it uses shared resources among several public clients which allows high utilization rate of resources leading to minimal waste. However, adopting public cloud raises security concerns since it is public. This would drive organizations with security concerns to adopt private cloud which is the least environmentally sustainable since the resources are procured by the organizations and typically not optimized for efficiency in terms of utilization and energy. Organizations concerning security issues may refer to adopting the community cloud which is sharing resources among a group with common interests. This provides slightly higher security measures as compared to public cloud while achieving higher environmental sustainability as compared to private cloud. However, if community cloud is not an option, organizations may adopt the hybrid cloud as a measure to keep critical information on the private cloud while storing most of the non-essential files on the public cloud. This improves slightly on the

environmental sustainability while providing maximum security for the sensitive data and critical applications.

V. Cloud Features In Sustainable Development

There are many features associated with the adoption of cloud computing. However, three features are identified to be most relevant to achieving sustainable development. These features are resource pooling, rapid elasticity, and broad network access.

A. Resource Pooling

The resource pooling feature facilitates the multi-tenancy model where multiple cloud users would share the utilization of the cloud infrastructures. The cloud infrastructures would be assigned dynamically according to user demand. This allows cloud infrastructures to achieve high utilization rate which can benefit environment sustainability by efficiently allocating resources and shared among multiple users. In addition, this reduces the need for cloud users to procure physical infrastructures leading to reduction in generation of e-waste. This feature contributes to sustainable development by reducing the reliance of on-premises infrastructures. Provision of computing infrastructure is shifted to the cloud service providers which are equipped with highly optimized facilities to ensure high efficiency in resources usage leading to reducing the use of resources and energy.

B. Rapid Elasticity

The rapid elasticity facilitates the on-demand request of additional computing resources for temporary measure. This allows organizations to procure computing infrastructures that are sufficient for handling normal workloads without the need to procure additional infrastructures just to handle the temporary excess workload. Procuring additional infrastructures introduce additional costs and wastage since it is not efficiently utilized. The rapid elasticity feature would ensure the existing computing infrastructures remain relatively high utilization while acting as a cost-effective measure to mitigate the risk of cloud bursting. This feature contributes to sustainable development by reducing the need to procure additional infrastructures that is not efficiently utilized by the organizations.

C. Broad Network Access

The broad network access facilitates the accessibility of cloud applications using any devices at any location via an internet connection. This enables remote working feature which enable users to perform work without the need to commute to offices. The reduced need of commuting to offices would directly translate to reducing the emissions generated from transportations. In addition, users would save a significant amount of time and energy due to lesser commuting. In the long run, this would benefit the mental health of users while contributing lesser emission to the environment. This feature contributes to sustainable development by reducing emissions to the environment by providing employees the option to work from any location without the need to enter the office while encouraging better mental health for users.

VI. Strategies Of Cloud Service Providers in Sustainable Development

The cloud provider plays a significant role in facilitating the achievement of sustainable development. As more and more consumers are adopting the cloud solution, cloud providers would need to increase cloud capacity to meet the demands. This translates into more data centers being built around the globe. It is known that data centers tend to consume large amount of energy to provide power and cooling to the servers. However, older data centers tend to rely on non-renewable energy as their main energy source which is not environmentally sustainable. Therefore, with the establishment of the global goal to reach carbon neutrality, cloud providers have started to implement more environmentally sustainable facilities such as the switch to using renewable energy sources and better power efficiency management to reduce carbon footprint. The following section discusses the approaches adopted by the three biggest cloud providers namely Amazon, Microsoft, and Google as part of their responsibility in facilitating the transition to carbon neutrality.

A. Amazon Web Service (AWS)

Various approaches are initiated by Amazon as part of their continuous effort to achieve net-zero carbon by 2040. As for the cloud platform AWS, Amazon has focused on implementing innovated cloud infrastructures of better efficiency along with the aim to achieve 100% usage of renewable energy to power all operations by year 2025 [8]. Amazon to date has procured over 300 wind and solar energy projects across the globe as an initiative to transition into using renewable energy. In addition, Amazon has continuously invested in innovations related to renewable energy and energy storage projects.

In the data centers of AWS, power efficiency and availability are improved by replacing the central uninterruptible power supply (UPS) to the use of small custom battery packs integrated into each individual rack, which reduces the energy conversion loss by 35% [9]. In addition, AWS servers utilize an enhanced version of processors that provides better performance per watt which further increases the energy efficiency in their data centers.

Data centers produce a lot of heat and would require a lot of cooling effort to ensure the equipment are running at optimal efficiency. The main approach for AWS to cool off their data centers is using water. However, water scarcity is a huge potential future problem and Amazon has adopted several strategies to utilize water for cooling their data centers more sustainably [10]. Firstly, Amazon uses evaporative cooling systems to minimize the water used. Secondly, Amazon uses recycled water specifically non-potable water instead of using fresh water for cooling the data centers. Thirdly, Amazon implemented modular water treatment facilities on site for treating the recycled water to further reduce the reliance on fresh water. And lastly, Amazon developed metrics to monitor water efficiency and real-time usage to identify better water reduction technologies.

B. Microsoft Azure

Microsoft Azure has committed to achieving environmental sustainability through four key aspects namely

carbon, water, waste, and ecosystem [11]. Where, Microsoft aims to operate on fully renewable energy by 2025, replenish more fresh water to the environment as compared to the consumption by 2030, full implementation of zero-waste principles by 2030, and net-zero deforestation.

Several strategies involving improving the efficiency of power supplies and server cooling is adopted at the data centers from Microsoft. Microsoft uses liquid cooling for the processors but in a unique way. Portion of the server blades where the processing chips are situated are immersed directly in a special cooling fluid called low-boil dielectric fluid. Heat generated from the chips are directly absorbed by the liquid turning it into vapor and to be recaptured for recycling and reuse. This setup allows more server blades to be placed closer together resulting in fewer server racks and suitable to be fit in a data center of a smaller configuration. In addition, Microsoft claims that the liquid immersion cooling technique is much more energy efficient and significantly reduces the water usage as compared to traditional method of cooling a data center [11].

Similar to Amazon, Microsoft have started the shift to using batteries as the backup power supply option from the traditional diesel generators. However, Microsoft has taken a step further by implementing a grid-interactive UPS where additional energy not required by the data centers are redirected back to the grid to supply electricity for the nearby community. By implementing batteries as the backup supply option, Microsoft data centers can further reduce emissions and provide electricity back to the grids while maintaining data centers with high availability. Data centers from Microsoft are still in the transition phase to using battery backup option. Therefore, for data centers that are still using the diesel generators, Microsoft have started to replace diesel fuel to an alternative cleaner natural gas which generates less emissions.

C. Google Cloud Platform

Several approaches to achieving environmental sustainability by Google has been implemented with the aim to achieve full utilization of renewable energy by 2030 for all data centers from Google around the globe. Like Microsoft, Google is committed to replenish more water than consuming it by 2030. For backup power option in data centers, Google has implemented similar solution as Microsoft by shifting to the use of battery packs and connecting to the grid as a way to redirect excess energy from the data centers back to the local community [12]. This movement is still in its infancy stage, but Google has committed to implement this strategy for their data centers around the globe. In addition, Google has developed a collection of tools that allow Google cloud consumers to monitor and track carbon emissions when using Google cloud resources. This enables consumers to understand their carbon usage thus are more aware of their impact on environmental sustainability which allow appropriate actions to be taken to reduce carbon footprint.

D. Discussion

All three cloud providers have implemented various strategies in their data centers as part of their responsibility in achieving environmental sustainability. The common focus is to reduce resources consumption while positively contribute back to the community and environment. It was observed that all three providers are highly committed on improving the power and water usage efficiency in their data centers. As these two components contributes significant impact to the environment.

All three cloud providers are increasingly implementing the use of solar and wind energy as their renewable energy resources. Although wind energy is cleaner than the traditional fossil fuels, a decommissioned windmill can generate a lot of waste which are not recyclable such as the blades of the windmill [13]. These composite blades are not recyclable and have very little reuse value once disposed. While for the solar farms, the manufacturing of solar panels can involve the use of finite earth minerals and energy intensive production process which can have an impact to the environment [14]. In overall, all three providers are increasing the adoption of renewable energies to reduce their emission to the environment.

Looking at the strategy each provider cools their data centers, it is observed that Microsoft's method of immersion cooling is much more environmentally friendly and with better efficiency. However, it will be difficult for older data centers to transition into adopting this strategy as it would require an overhaul of existing server racks to adapt to the liquid immersion cooling method. This method can be implemented into newer data centers that are yet to be built to help increase efficiency and reducing the reliance on fresh water.

VII. Challenges Of Adopting Cloud Computing

The adoption of cloud computing is perceived to be a positive development for organizations and the environment, but from the big picture it is not completely clean and environmentally friendly. The cloud service providers are implementing various strategies as part of their duty in achieving environmental sustainability. However, at the granular level, choices of design and technology implementation in organizations may still be limited in terms of sustainability and would still provide a massive impact to the environment [15]. As organizations may not be mindful that their choices of digital tools and practices may carry unintended consequences to the environment. Better awareness is to be introduced to organizations to educate on implementing carbon-conscious digital tools and practices to further reduce impact to the environment.

As more organizations adopt cloud computing, the expectation of cloud service providers to provide high reliability and availability of cloud service increases. Very few organizations have backup systems to rely on if cloud outages were to occur. This would bring major consequences to organizations and lowered the confidence towards cloud providers. Therefore, this has driven cloud service providers to constantly innovate and improve on facilities to meet the service level agreements. However, innovations that can align with both sustainability and performance can be difficult to achieve which may delay the overall innovation process resulting in risks to be faced by both cloud providers and consumers.

The adoption of cloud computing is not the only solution. Organizations that have predictable requirements of

computing resources can stick to the option of procuring on-premises infrastructures as it may be more cost effective than subscribing to cloud services. As paying for cloud computing is not always cheaper than using their own computing infrastructures. This led to the increased use of resources in organizations that may not have the same level of environmentally sustainable facilities as compared to major cloud service providers thus resulting in greater emissions.

A major challenge faced by organizations when migrating to the cloud is the compatibility of existing applications with the cloud environment. Existing applications may need to rewrite and be optimized to be hosted in the cloud which may introduce complexity and additional costs. This would deter organizations from adopting cloud and would continue working with existing infrastructures that may be inefficient in terms of energy and performance leading to greater emissions. In the scenario where the organization has chosen to migrate to the cloud, a successful migration would signify a new system to the organization. This introduces unfamiliarity which would require additional training and resources to educate staffs on operating on the new system.

For organizations dealing with highly sensitive data and mission critical applications, they are more reluctant to adopt cloud computing from general cloud service providers due to security concerns. By migrating to the cloud, new security threats may be introduced that may arise from the data centers. The organizations are concern that any security breach at the data center would cause an irreversible consequence that may lead to the downfall of the organization. In addition, organizations are generally concern that competitors are using the same cloud resources resulting in the usage of same application that would diminish the chances of obtaining competitive advantage.

Another challenge to be considered after migration to the cloud is the accessibility to the applications and resources which can only be done through the internet. Therefore, organizations would need to set up proper networking infrastructures to ensure continuous and smooth operation is achieved. However, there can be issue of latency depending on where the application is hosted, as data centers can be situated on various locations around the globe. In addition, there may be issue of data sovereignty where data is confined by laws and governance of the nation. This results in limited choices of data centers available for the cloud consumers. Which may not have the option to select data centers that are more environmentally conscious. Not every data center has fully adopted the green initiative thus cloud consumers would need to be aware and identify data centers that are aligned with the sustainable development. However, if choices of greener data center are located far from the organization, issue of high latency may be experienced which would deter organizations from selecting the greener option.

VIII. Conclusion

This paper reviewed the benefits and impacts of cloud computing onto sustainable development. Environmental sustainability is an important goal to be achieved through the collaboration of all levels. The adoption of cloud computing in general is able to contribute to the increase of environmental sustainability. This can be observed through the various initiatives implemented by the cloud service providers to continuously improve efficiencies and resource utilization in the data centers with the consideration to reduce impact to the environment and providing back to the community. However, further improvements can be made to increase sustainability at the granular level where cloud consumers would need to increase their awareness on the actions and choices taken as it may introduce inefficiencies resulting in negatively impacting the environment. Increasing the awareness about sustainable development to cloud consumers is highly encouraged to ensure the effectiveness and efficiency of resources utilization can be improved, ensuring a better world for the current and coming generations.

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