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Green Cloud Computing and Economics of the Cloud: Moving towards Sustainable Future

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***Abstract*— With the increasing popularity of cloud computing services, it is becoming more and more important for cloud service providers to ensure that they fulfill their responsibility towards the society by minimizing the environmental impact of their business operations. The high electricity needs of datacenters make cloud computing companies consume an extremely large amount of electricity. To deal with this issue, these companies are starting to adopt renewable sources of energy to power their datacenters for reducing the negative environmental impact. The purpose of this paper is to review the green Cloud and economic benefits of green Cloud. Therefore, it has been found that dynamic provisioning, multi-tenancy, server utilization and datacenter efficiency are major factors that could be used to minimize the power consumption while increasing environmental sustainability. The paper concludes that (a) economical viability of green Cloud adoption, (b) the location datacenter that needs to be considered during green Cloud adoption, (c) the utility providers that provide green energy at competitive prices, and (d) the generation of energy at on-site will be costly, but mixes of energy sources such as wind and coal will cost companies 13% more.**

Keywords—green cloud computing; sustainability; economic benefits; viability

I. Introduction

Cloud computing has been recognized as a new model that can be used to host resources outside of the company premises [1]. Furthermore, a National Institute of Standard and Technology (NIST) defined Cloud computing as a model for enabling convenient, on-demand network access to a shared pool of configurable computing resources (such as networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction [2, 3]. Hence, Cloud computing is one of the popular technologies that has taken attention of its users worldwide [4]. Furthermore, Cloud computing has implicated the way that people work, collaborate and share knowledge with a rest of the world regardless of the physical location [5].

Jena et al. [6] suggest that a rapid increase in cloud computing demand has resulted increase datacenters, and associated infrastructure. They argue that this increased demand has increased a large amount of energy consumption to operate the Cloud infrastructure. However, it has resulted increased carbon emission, and contradictory term "Green Cloud computing being GREEN".

The Cloud providers, however, who is providing Cloud services and infrastructure with an immense efficiency of energy consumption as much as possible with no or minimal environmental impacts have been identified as a "Green Cloud computing" [7]. Thus, terminology of Green Cloud Computing should include the dimensions of environmental sustainability, economics of energy efficiency, and the total cost of ownership says [7]. Jena et al. [6] articulated Green Cloud computing as an adaptive energy efficient, environmentally responsible use of computer resources with minimized waste. Thus, it has been estimated that US organizations could move their traditional IT systems to cloud computing and save approximately 12.3 billion dollars by 2020 in energy costs, which is equivalent to 200 billion barrels of oil, and reduce carbon emission subsequently [6]. It is found that as at 2012, all the datacenters that have been hosting or providing Cloud services have consumed approximately 30 billion watts of electricity, which is equivalent to the output of 30 nuclear power plants [4]. However, Cloud computing has a potential to emerge as a powerful technology which can contribute to green IT and carbon emissions [8], and endeavoring to reduce carbon emission could make environmentally friendly "Green" clouds in the near future [4].

This paper presents a review of green Cloud computing, costs of different sources of energy, impact of datacentre location, economical advantage of generating energy on-site, economical viability of green Cloud computing and environmental sustainability of green Cloud computing.

II. Literature Review

Cloud computing has become an important IT strategy for companies as it helps achieve economies of scale, streamline processes and lowers costs by allowing companies to do away with the hassle of having its own datacenters and servers leading to cost savings of about 30% [9]. In a survey of 930 IT professionals conducted by the Cloud management company RightScale, 93% of the respondents stated that they are using cloud computing at work [10]. Fig. 1 summarizes the treands of Cloud adoption, and provides information on the Cloud models that are more in demand than the others.

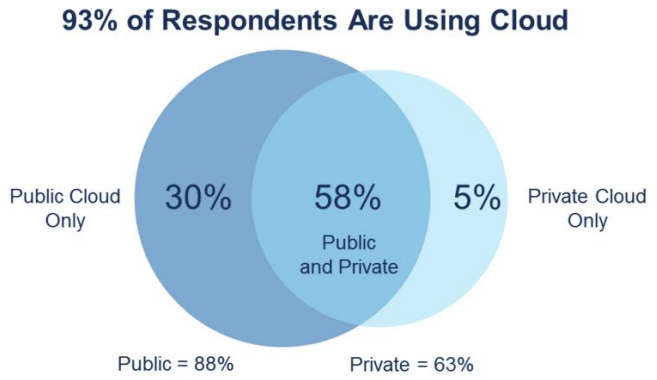

Fig. 1. Cloud computing trends

A KPMG research [11] has also found that mass adoption of cloud computing services will lead to savings of 25% of operating expenses and 50% of capital expenditure, which can greatly increase the gross domestic product (GDP) of a country. It is found that within ten years, these savings will contribute an additional AUD 3.2 billion per annum to the Australian GDP [11]. As a result, the development and implementation of Cloud computing is one of the important strategies adopted by companies for achieving competitiveness.

Even though Cloud computing is important for companies' success, rising levels of global warming and environmental concerns have made companies more aware of their carbon footprint, energy consumption and their e-waste, aiming to be sustainable businesses instead of just profitable. Sustainability depends on balancing the economic, social and environmental outcomes with a sustainable business being one that is economically viable, socially equitable and environmentally friendly [12]. Fig. 2 summarizes the importance of socio-economical factors which are positively contributing to the economical sustainability.

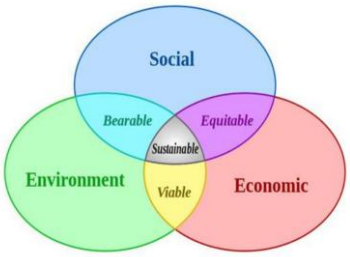

Fig . 2. Confluence of three constituent parts

Cloud computing services, too, have to be economically viable and environmentally friendly, if they wish to continue success and popularity. While the economic benefits of Cloud computing are well researched and proven [9, 11], the environmental effect has so far been ignored. In a day and age where individuals and companies both, carefully select their electronics and other equipments based on how "green" and how energy efficient they are, it is surprising that most people do not think about the carbon footprint of the online services they are using.

Cloud computing service providers have large datacenters that house their servers that are used to host their cloud services. Servers require a large amount of uninterrupted electricity to function smoothly, which is evident from the fact that the combined energy consumption of datacenters globally is 662 billion KwH, which ranks fifth if compared to the energy consumption of countries, as shown in Fig. 3.

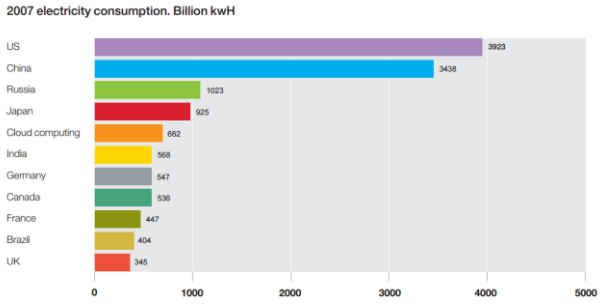

Fig. 3. The 2007 electricity consumption

The high electricity consumption is due to the fact that a typical datacenter usually consumes 100-200 times more electricity than a standard commercial building [14]. 40% of the datacenters are located in the USA, which makes American datacenters the largest consumers of electricity. In 2013, American datacenters consumed 91 Billion kWh of electricity, which is an annual output of approximately 34 coal fired power plants [15]. The sheer magnitude of power consumption by datacenters can be understood from the fact that 91 Billion kWh of electricity is enough to provide two years worth of energy to all the households in New York [15]. In comparison, Australian datacenters consume only 2-3 billion kWh of electricity, but this is still equivalent to 1.5% of the nation's total energy consumption [16]. Thus, Fig. 4 presents a summary on how the ICT sector has contributed to carbon emission.

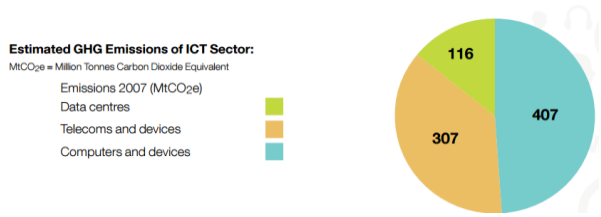

Fig. 4. Estimated GHG emission of ICT sector

Currently, datacenters and cloud computing companies use a metric known as power usage effectiveness (PUE) to determine how green they are. PUE is the ratio of the total amount of energy used by a facility to the energy used by IT

equipment. A PUE of 1 indicates that the company is 100% energy efficient. However, PUE is an incomplete measure of how environment friendly an organization is, as it fails to take into account the carbon emissions [13]. Mass [17] pointed out that as per IDC (International Data Corporation) report estimation, global cloud service spending was predicted to be increased from 16 billion to 42 billion dollars in 2012 with 27% of global annual growth. Therefore, many companies not only recognize that cloud computing is a useful solution for their needs, but also as a new business opportunity [18]. However, Gartner[19] noted that global ICT industry generates only 2% of the total global carbon emissions, which is almost equal to a global aviation industry. As per Eurostat [20] report indicates, the European Union has agreed to reduce the carbon emission by 15% - 30% before 2020 to keep the global temperature increases below 2^0C. Therefore, it can be assumed that the adoption of green cloud has been driven by European agreements. Thus, energy consumption and carbon emission by cloud infrastructures has become a victim of this and a key environmental concern [18].

The key question, though, is whether it is economically viable for cloud computing companies to go completely green. Their popularity depends on their low-priced services which is largely a result of economies of scale. Would opting for a greener company strategy increase their costs and therefore their price? If so, it would make the option economically unviable and cause companies to continue using non-environmentally friendly policies. This paper aims to answer these questions and study the economics of green cloud computing.

III. Discussion

Based on the literature review presented in Section II, several issues can be found that are critical for the adoption of green cloud computing with an economical benefits with an environmental sustainability. Therefore, those factors are discussed in details below;

Costs of different sources of energy

The biggest choices that a cloud service provider has to make while devising their green strategy is the source of electricity [13]. Non-renewable sources like coal and natural gas are harmful to the environment as they cause natural resources to dwindle as well as release carbon dioxide and other greenhouse gases. Most electric utility companies currently use coal and natural gas as their primary fuel source mainly due to the fact that fossil fuels are cheaper than renewable energy. Solar energy costs 7.2 cents per kWh while coal costs 6.6 cents per kWh and natural gas 6.1 cents per kWh[21]. However, most governments offer subsidies and tax incentives for renewable energy, which lower prices considerably. Subsidized solar energy costs about 5.6 cents per kWh while subsidized wind energy costs only about 1.3 cents per kWh [21], on an average. The problem, however, is that very few utility companies offer their customers renewable energy and depending on the location of a datacenter, many times the only option available is to use electricity generated from non-renewable sources. However, according to Accenture [22] explains that moving business applications to cloud could reduce the carbon footprint considerably. According to Accenture statistics [22], Small businesses have reduced their carbon emission by 90%, medium sized companies have reduced their carbon footprint between 60%-90% while large enterprise have decreased their carbon footprint approximately between 30%-60%.

Impact of location

It is found that the impact of location plays a significant role in the development and application of Cloud computing services. Therefore, whether or not it is economically viable for a Cloud computing service to use renewable sources of energy depends largely on location. Two of the most popular location choices for datacenters in the USA is North Carolina and Virginia. Unfortunately, these areas also have one of the dirtiest electric grids in the country, deriving only 2.5%-4% of their electricity from renewable sources [13]. Apple, Facebook, Google, Microsoft, IBM and many other IT firms have their datacenters here, making the cloud services offered by all of them non-environment friendly. So why did these companies choose to build their datacenters here knowing that they would contribute towards environmental damage? To reduce their overall costs and be more profitable.

Duke Energy, the primary electricity provider in North Carolina, woos IT companies by agreeing to provide them electricity at dirt cheap prices. It provides electricity to industrial customers at prices as low as 4 cents per kWh [13], which is much less than the national average. Such pricing strategies and the profit maximization aim of companies together combines to create an extremely dangerous combination - an economically lucrative option that is harmful to the environment. More and more companies are lured by the low prices leading to greater environmental damage. While it is true that the initial costs of fossil fuel powered servers are low, the long term economic impact to the society is very high. In 2013 research, it was found that long term health related economic impact of fossil fuels is almost USD 800 billion annually [23].

Economics of generating renewable energy on-site

For Cloud service providers who wish to use renewable sources of energy to power their datacenters, but are unable to find a green utility provider, the only option is to have their own solar or wind farms. Wind farms, due to their massive turbines, require larger land areas than solar farms. Typically, the area required for a solar farm is 9.41 sqm per kWh, while the area required for a wind farm is 18.21 sqm per kW [24] . For a medium sized datacenter with a requirement of 50 MW, the company will need a 470,500 sqm of land for a solar farm and a 910,500 sqm of land for a wind farm. This additional need for land will definitely add to the overall cost of services provided by a cloud computing company. However, it must be noted that the installed price of Solar energy, on an average, is USD 5.5 / W [25] and the installed price of wind energy is USD 1.75 / W [26] which makes wind energy cost less than half of solar energy, not taking into account the land price.

In order to understand how using renewable energy for powering cloud computing services affects its economics, it is necessary to take into consideration all these factors. Very

little research has been conducted till a date on the costs involved in building a green cloud computing network. The research by [24] is the only research that studies this topic in detail. It states that a datacenter powered by wind energy produced by its own wind farm costs 4% - 25% more than one that is powered by coal [24]. Datacenters powered by electricity from their own solar farms cost 25%-82% more than those powered by coal [24]. The researchers further considered the impact of net metering, energy storage and using a mix of renewable and non-renewable. They found that while the revenue generated from net metering is not so significant, it does help to lower costs significantly since the extra energy generated can be stored with the power grid, thereby doing away with the need of over provisioning to deal with variability in solar / wind energy [24].

Economic Viability of using green energy

The most cost effective energy mix of renewable energy is being produced on site [24], whereby it is 50% wind energy, and 50% fossil fuel, which costs only 13% more than using 100% fossil fuel electricity [24]. However, it is noted that even a 13% increase in costs is a significant amount in a competitive market like Cloud computing, where customers choose the service mainly on the basis of price. If a business wishes to be economically profitable as well as environmentally friendly, the planning for the same should begin before a datacenter is set up. It is extremely important to choose a location where renewable energy is available at competitive prices through an energy provider. For example, in the Pacific Northwest, the Bonneville Power Administration (BPA) provides an energy mix consisting of 81% renewable energy, 9% nuclear energy and 10% fossil fuels at the competitive price of 3.5 cents per kWh [27], which is actually cheaper than the price being offered by coal powered utility providers.

Green Cloud and environmental sustainability

Even though there is enormous belief in the community that Cloud computing may have contributed more to increase the carbon emission while consuming a large amount of energy by its application and infrastructure, there is an invisible green layer underneath. Fairweather [28] suggests that since global ICT is contributing only 3% of the total carbon emission, use of energy does not a similarity associate with the carbon emission. However, Fairweather [28] noted that "the bulk of life cycle enery use for many computers is in production", and "use impacts for energy and global warning can be considered to be at least as important as those of materials and manufacturing" [29]. Meanwhile, Garg and Buyya [18] suggest that the global ICT contribution of carbon footprint can be reduce by implementing new technologies and concept that could utilize the resources and manage energy consumption efficently than traditional computing. Buyya et al. [30] suggest that greenCloud computing is not only expected to provide efficent processing and the best utilization of computer infrastructure, but also need to reduce the use of energy consumptions by its application and infrastructures. Buyya et al. [30] also argue that sustainability of future growth of Cloud computing can be achieved only by succeeding essentials goals.

Hence, Accenture Microsoft Report [22] has identified four key factors that could be used to minimize the environmental impact by lowering the energy usage of cloud computing. Furthermore, it is expected that companies are able to reduce carbon emission by 30% per user by moving traditional applications to a Cloud environment. Table 1 presents the key factors that could be used to save energy while achieving green Cloud goals. They include dynamic provisioning, multi-tenancy, server utilization and datacenter efficiency.

Dynamic provisioning: could be used to deploy more servers, networking and storage infrastructure as needed to meet the demands. Hence, datacentres will only maintain the servers according to the demand that they have at any point, which could result in lowering the energy consumption [18].

Multi-tenancy architecture will allow Cloud providers to serve multiple companies using same infrastructure simultaneously. By doing this, cloud providers could be able to reduce the energy consumption which is associated with cloud infrastructure, and overall carbon emission.

Server utilization provides efficient server utilization to help maximize the energy savings. Cloud providers may try to utilize their infrastructure at least up to 70% than traditional on-premise server utilization which is somewhere 5%-10% average [18]. Thus, this will reduce the number of active servers; increase the number of users per server while processing more workloads at optimal levels.

Datacenter efficiency uses the most state-of-art technologies such as modular containers, water or air based cooling, advanced power management through power supply optimization in order for Cloud providers to be able to use energy more efficiently. Thus, that will help to reduce a significant percentage of carbon emission.

Current strategies for green cloud computing

Companies that have chosen to give top-most priority to the environment have decided to build their datacenters in countries where utility companies focus on renewable energy, like Sweden, where the electricity provided consists of 60% renewable energy [13]. Facebook, one of the companies that have pledged to go completely green, chose to have one of its datacenters in Lulea, Sweden, where most of the electricity provided is generated from a renewable source. A further benefit of having a datacenter in a cold country is that there is no need for elaborate cooling solutions since the freezing outside air can be pumped through pipelines for efficient cooling. EVRY, a Norwegian IT solution company that also provides cloud computing services, is one of the few cloud service providers that uses 100% renewable energy, making it very environmentally friendly company.

TABLE I. KEY FACTORS OF LOWER ENERGY CONSUMPTION

Key factors	Sub criteria	Sources
Dynamic provisioning	Server provisioning	Goswami, et al. (2013), Lent (2016)
	Network provisioning	Pompili et al. (2015)
	Storage infrastructure	Lent (2016); Wood et al.(2015)
	Cloud deployment	Lent (2016), Wood et al. (2015)
	Lowering energy consumption	Lim (2015); Zuo et al. (2015)
Multi-tenancy	Infrastructure sharing	Tolosana-Calasanz et al. (2016)
	Reduce energy consumption	Lo et al. (2015)
	Revenue and economics of cloud economics of cloud	Moens et al. (2015)
	Utilization of hardware and applications	Moens et al.(2014); Chunlin et al. (2015)
Server utilization	Server utilization	Totok and Karamcheti (2010)
	Consumer energy consumption	Nanath and Pillai (2013)
	Reduce carbon emission	Ting-Kuo and Wei-Jung (2014), Garg et al. (2009), Mandal et al. (2013)
	Progress of energy efficiency	Sankar et al. (2013)
	On-premise servers	Carcary et al. (2014),Sandhu and Sood (2015), Nanath and Pillai (2013)
	Processing more work load	Reddy and Kumar (2014), Yang, Y. (2011)
Datacentre efficiency	State-of-art technology	Cho & Kim (2016)
	Advanced power management	Uddin et al. (2015)
	Power supply optimization	Cho et al. (2015)

The major findings from the above literature review are as follows:

- It is economically viable for Cloud computing companies to adopt greener practices
- The location of datacenters should be chosen carefully such that renewable energy is available at competitive prices
- Utility providers in the Pacific Northwest and countries such as Sweden and Iceland, offer renewable energy to customers at similar rates of coal powered electricity
- Using on-site generated renewable energy is slightly costlier, with an electricity mix of 50% wind and 50% coal costing 13% more than 100% coal

There is a convincing requirement to consider environment factors during the adoption of cloud computing. However, adopting green cloud computing while minimizing the environmental factors are not easy as see. Murugesan [7] noted the Green cloud is not just creating an energy efficient IT systems, though it is an important part of a green life cycle. Thus, Green IT is all about creating energy-efficient, environmentally sustainable business process and practices. Since global IT industries add only 2% - 3% pollution to the total global carbon emission, a vast majority of pollution comes from non-IT sources. Therefore, the areas of the economy must consider the energy efficient savings by improving their business processes towards to environmental sustainability. Therefore, key findings identified in this study will be helpful for companies to consider during the development of green cloud strategy.

IV. CONCLUSION & FUTURE DIRECTION

Customers are vigilantly for competitive cloud prices for their business requirements while keeping environmental sustainability. Thus, this situation has increased the pressure on cloud service providers to be creative on the triple bottom line instead of the only profit maximization. Since datacenters consume extremely large amounts of electricity, making them more energy efficient and using renewable sources to power it can make a huge difference to the overall environmental impact of a cloud computing firm. Some studies have found that using a mixture of energy sources such as on-premise wind farm energy and fossil fuel form energy could increase the overall costs by only 13%, but considerably reduces the carbon footprint. Generating their own renewable energy on a site may seem tedious, but if the utility provider has a net metering facility, then it can become an additional source of income while also providing energy storage for a peak season needs.

However, the more profitable option is to buy electricity from a green utility provider like BPA, which provides a greener energy mix at prices comparable to fossil fuel electricity or build a datacenter in a country where renewable energy is widely available at cheap prices. Therefore, it is definitely possible to have economically viable and profitable green Cloud computing company, but it requires companies to pursue their green strategy in all aspects of business, including the location of their datacenters, and the energy mix of electricity used.

In this review, four key factors have been identified as the most influential factors that could be used to minimize the overall environmental impacts. However, those factors were not discussed in details to find how those can contribute more

to achieve green cloud goals. Thus, this area needed to explore more in future studies.

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