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A Comprehensive study on Cloud Green Computing: To Reduce Carbon Footprints Using Clouds

Chiranjeeb Roy Chowdhury[1], Arindam Chatterjee[2], Alap Sardar[3], Shalabh Agarwal[4], Asoke Nath[5]
Department of Computer Science, St. Xavier's College (Autonomous), Kolkata, WB, India.

Abstract

Cloud computing and Green computing are two most emergent areas in information communication technology (ICT) with immense applications in the entire globe. The future trends of ICT will be more towards cloud computing and green computing. Due to tremendous improvements in computer networks now the people prefer the Network-based computing instead of doing something in an in-house based computing. In any business sector daily business and individual computing are now migrating from individual hard drives to internet servers. The concept of cloud computing has dramatically changed the classical method of computation. To save space, time and money, the people perform computation in Internet server instead of doing computation on a desktop or a laptop. The main issue in cloud computing is to save resources, time, cost and duplication of same data. Instead of upgrading software in a standalone machine, one can use the software in the cloud in web and save energy and money. In the present paper the authors tried to analyze the energy consumption of Cloud Computing by studying the clouds maintained by certain organizations and observing the energy benefits that they derive. The authors have also made study by which the carbon footprint can be reduced through Green Cloud Computing.

Keywords

Cloud Computing, Green Cloud Computing, Green Software Engineering.

1. Introduction

Cloud computing is 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 as stated in NIST[1]. The advantage of cloud computing is that the users will be able to access applications and data on the cloud from anywhere in the globe, making the cloud appear as a single point of access.

Cloud computing has begun to catch on and will soon spread like a wildfire. There are many organizations offering cloud services. Amazon Elastic Compute Cloud (EC2)[2], is a web service that provides resizable compute capacity in the cloud. It is designed to make web-scale computing easier for developers. With Microsoft Live Mesh[3], users can keep copies of documents, photos and other files on the 5 GB of free storage space available in the cloud and work with these files on the web from any computer with Live Mesh installed. Microsoft Windows Azure[4], enables users to quickly build, deploy and manage applications across a global network of Microsoft managed data centers. The applications can be built using any operating system, language or tool, and can be integrated into an existing IT environment.

To most people, the internet is a very abstract concept. Many are unaware of its corporeality, since the fact that it is just a hugely distributed network with all its data stored in various data centers scattered across the world is unknown to the general public. Hence, the huge carbon footprint (the total set of greenhouse gas emissions caused by an organization, event, product or person[5]) of the internet goes unnoticed. According to The Guardian[6], data centers are responsible for 0.5% of global CO_2 emissions. If we also consider that around 50% of the emissions due to the world's computers are for internet based activities, then the carbon footprint of the internet rises to 1% of the global CO_2 emissions. In other words, the internet releases around 300 million tons of CO_2; equivalent to the total consumption of coal, oil and gas by Turkey or Poland in one year, or more than half of those burned in the United kingdom. In a report by Gartner [7], ICT industry is responsible for 2% of global CO_2 emissions, making it at par with the aviation industry. We are all aware of the fact that world fossil fuel reserves are rapidly depleting, thus forcing mankind to rethink his wasteful practices in order to assure his

survival. Thus, mankind must turn to technologies that can not only reduce energy consumption and wastage, but also reduce the carbon footprint of his actions. In other words, Green Technologies must be adopted.

We thus come to the concept of Green Software Engineering (GSE). GSE is an approach to developing, operating and maintaining software following certain engineering principles that also recognizes and counteracts threats to the environment [8]. GSE can help reduce damage to the environment in various ways. For example, removing need for printouts and post, using e-books, reducing energy consumption in data centers, reducing CPU cycles generated by software code, extensively using video conferencing, cloud computing and so on.

We will now look into the different ways in which the energy usage of cloud computing can be decreased thereby helping to reduce the carbon footprint of the ICT sector. Some metrics which are used to measure the effectiveness of data centers will also be examined. We will also study a few 'green' clouds maintained by some organizations around the world and observe their adopted practices. Finally, we conclude with the future of green cloud computing and any scope of further research.

2. Energy Benefits Of Cloud Computing

Here we shall see how the environment can benefit from extensive but efficient use of cloud computing. There are a large number of ways these energy savings can be achieved and we elicit the major points.

Resource Virtualization is heavily used in cloud computing thereby reducing the total physical server footprint[9]. Virtualization is a technique that allows a single server to run multiple operating system images simultaneously. Hence, less equipment is needed which reduces e-waste as well as energy consumption. Server virtualization is implemented at 90% of all IT organizations globally.
The pay-per-use or pay-as-you-go nature of cloud computing, forces users to consume only the resources that they need and also to use it for limited durations of time. This helps to reduce wastage of computing power and resources, thereby helping to increase energy and resource efficiency.

Cloud computing also helps to avoid duplication of data, to a certain extent. Large organizations (who do not use cloud computing) spread over many countries, may need to have some amount of information available at all times to all their offices. The only way to achieve this (without setting up a costly, centralized server) is to have copies of the required information at many servers throughout their offices. This duplication of data can be avoided by using cloud computing. If the organization used public cloud services, or even had a private cloud system of their own, then all the information would be present only at the cloud and everyone would be able to access the data easily.

A study by the Carbon Disclosure Project[10], supported by AT&T, states that companies which adopt cloud computing have reduced carbon emissions, lower energy consumption and decreased expenditure while having improved operational efficiency. It is estimated that by 2020, annual energy savings of $12.3 billion and annual carbon reductions equivalent to 200 million barrels of crude oil can be achieved, as a result of large US companies migrating to cloud computing.

From a study conducted by Microsoft, Accenture and WSP[11], it is seen that when organizations move towards using established public cloud services over their own IT infrastructure, then the smaller is the organization the more is the energy and carbon savings. For small organizations of around 100 users, savings of 90% or more can be achieved while for larger organizations of 10,000 users savings are around 30%. The study also went on to show that if around 50,000 email users in North America and Europe can be moved to a public cloud managed by Microsoft, then a decrease of around 32% in net carbon emissions can be avoided. Thus, we see that as more people shift to cloud based e-mail services, like Gmail, the energy savings increase manifold.

The reason we can see such large energy savings when organizations move to cloud based services is due to the low server utilization levels of most companies. When organizations maintain their own data, e-mail servers and IT infrastructures then, more often than not, the servers are utilized to only half of their true capacity. The remaining storage space of the servers gets wasted. But the companies cannot provide power to and run only the utilized part of the servers. Also, these organizations have to provide for cooling their servers, keep redundant backups, and so

on. As a whole, they have to expend a large amount of energy to run the servers and so a huge amount of energy gets wasted. On the other hand, if these organizations shift their services to clouds then an appreciable decrease in carbon emissions and energy wastage is seen, because the specialized data servers in public clouds are already well used and as more and more organizations join the cloud their utilization levels go up, thereby decreasing energy wastage dramatically. Also, individual cooling systems for every organization is not necessary.

Another benefit of cloud computing is that by storing as much information as possible in clouds in the digital format, we can slowly phase out their physical counterparts, if any. Books can be stored as e-books in a cloud, thereby eliminating their physical printing. Readers will just need to buy their digital copy and read it. Documents and reports of an organization can be digitized completely and stored in the cloud for all time access. File hosting and sharing services can extensively utilize cloud services. This may one day eliminate the need of portable storage devices, since all the information will be available in the cloud. All this is possible because the information in a cloud can be accessed from anywhere and is more or less available at all times. Hence, all the energy and materials needed to print thousands of books or hundreds of pages of documents can be saved and utilized elsewhere.

Thus we see that while some organizations and studies slam cloud computing as farcical, there is quite a lot of truth to its claim that it can bring about a large amount of energy savings and can help to protect the environment.

3. Metrics to Measure Power Utilisation

The metric which is most used to measure the power utilization of data centers is known as Power Usage Effectiveness (PUE). PUE is the ratio of total amount of power used by a computer data center facility to the power delivered to computing equipment [12]. It was developed by a consortium, The Green Grid.
PUE can be mathematically stated as,
PUE = Total Facility Power ÷ IT Equipment Power (1)
The ideal value of PUE is 1.0. It indicates 100% efficiency, i.e. all the power is used by IT equipments only.

According to a white paper published by The Green Grid[13], IT Equipment Power includes the load associated with all of the IT equipment used to monitor and control the data center. Total facility power, includes everything that supports the IT equipment load like the power delivery components (UPS, batteries, generators), cooling system components (chillers, computer room air conditioning units (CRACs), pumps, cooling towers), datacenter lighting, storage nodes, and so on.
Another metric Datacenter Infrastructure Efficiency (DCiE), is the reciprocal of PUE. It can be mathematically stated as,
DCiE = 1÷ PUE = IT Equipment Power ÷ Total Facility Power * 100% (2)

A PUE of 3.0 means that for every watt of IT power, 2 additional watts are consumed to cool and distribute power to the IT equipment. A DCiE value of 33% (equivalent to a PUE value of 3.0) means that the actual IT equipment consumes 33% of the power in the data center.

Unfortunately, PUE is not without its disadvantages [14], which are,

1. PUE is extremely location and time sensitive.
2. Data Centers tend to subtract certain factors to lower the PUE rating.
3. PUE was designed only for dedicated data centers.
4. PUE cannot be used as a metric to compare data centers for business purposes, but to improve their effective use of power.

In order to plug these loopholes of PUE, certain modifications are made to its definition yielding a different metric called PUE_X, where X is a value between 0-3. Some drawbacks, though, still remain. PUE or PUE_X is not a measure of true greenness but a metric of how well a data center manages its power. We thus come to the final metric, called Green Power Usage Effectiveness (GPUE), which was first proposed by the organization GreenQloud. It can be stated as,
GPUE = G * PUEx (3)

The factor G can be stated as,
$G = \sum$ (%Energy Source * (1 + Weight)) (4)
We are adding 1 with the weight so that the value of G is never less than 100% and so the value of GPUE is not less than PUE_X.

Thus, we see that GPUE will yield values in a larger range than PUE and hence has better resolution than the scale of PUE.

We will now see a comparison of the GPUEs of various organizations and their different data centers.

Table 1 : Comparison of Various Data Centres

Data Center	G	PUE_x	GPUE	% Energy
Google, Lenoir	1.630	1.21	1.97	50.5% Coal, 38.7% Nuclear
Google, Dallas	1.490	1.2	1.79	34% Coal, 3.3% Nuclear
Apple, North Carolina	1.630	1.5	2.44	50.5% Coal, 38.7% Nuclear
GreenQloud, Iceland	1.021	1.1	1.12	70% Hydro, 30% Geo
Microsoft, Chicago	1.819	1.22	2.22	72.8% Coal, 22.3% Nuclear
Microsoft, San Antonio	1.936	132	2.32	37.1% Coal
Yahoo, Lockport	1.497	1.16	1.74	21.0% Coal, 27.0% Nuclear
Yahoo, La Vista	1.834	1.5	2.75	73.5% Coal, 14.6% Nuclear

We can see from the above table that PUE_X is not a good enough metric. This is because, even though Microsoft data centers have a low value of PUE_X, its GPUE is much higher than Google or GreenQloud data centers, due to the fact that Microsoft data centers rely more on electricity generated by coal than other non-renewable sources.

Thus, GPUE has been established as a very good metric for measuring the greenness of data centers.

4. Case Study – Google

For our first case study we shall look into Google, which along with Yahoo and also Facebook, leads the movement in using renewable energy in their cloud services and also actively supporting policies that lead to greater investment in renewable energy. Almost all of Google's signature products – Gmail, Google Documents, Google Earth, Google Apps and others, are delivered from the cloud. According to Bill Wheil of Google[15], the problem of increasing greenhouse gas emissions cannot be mitigated by increased efficiency of energy production or usage, but by shifting to cleaner and renewable sources of energy.

We can see from the Greenpeace report[16], that Google uses 39.4% renewable energy, along with 28.7% coal and 15.3% nuclear energy. According to a report published by The Guardian[17], Google emits 1.5million tonnes of carbon annually but the energy consumption of its data centers is approximately 50% less than the industry average. Google's emissions are slightly higher than the country of Laos, and equivalent to the operational carbon footprint of the United Nations.

In the same report[17], we come across certain other values regarding Google's carbon footprint. Every search in Google has a carbon footprint of 0.2g of CO_2. Watching a video in YouTube for 10 minutes releases around 1g of CO_2, while Gmail releases 1.2kg of CO_2 per year for a typical user. Watching YouTube videos for three days straight, will consume the same amount of energy that is required to manufacture, package and ship a single DVD. Gmail is a huge contributor in energy savings. Small industries switching to Gmail can be almost 80 times more efficient than maintaining in-house email servers, because cloud based services use highly efficient data centers and operate at higher server utilization rates [18]. According to Google, a normal user releases around 1.46kg of CO2 by using all the services offered by Google, which is equivalent to mundane tasks like filling a deep bath or buying a bottle of imported wine. Google estimates that data centers worldwide use 1% of the world's generated electricity and Google uses only 1% of that amount[17]. Also, Google has a goal of procuring over one-third of its total energy from renewable sources, which it has almost achieved.

From a report by Google[19], we find out that Google purchases 13% renewable energy while 20% is already in the grid, thus taking its total percentage of renewable energy to 33%. Solar panels produce around 3 million kWh of green energy every year at Google's Mountain View campus. Their data centers use only 50% of the energy that most other data centers require.

From the above discussion, the only apparent conclusion that we can arrive at is that Google is trying its best to help protect the environment and promote Green Cloud Computing and from the

figures it seems that Google is one of the most successful organizations to help use and promote Green Computing.

5. Case Study – GreenQloud

GreenQloud is a cloud computing organization founded in 2010 and based in Reykjavik, Iceland. It offers 'Truly Green™' cloud computing services powered by emission free energy sources[20]. It is both an Infrastructure as a Service (IaaS) and a Platform as a Service (PaaS) company.

GreenQloud offers public cloud services including, carbon neutral cloud server hosting, online storage, backup and cloud based computing and high performance computing services to companies and consumers. Like most other public clouds, it is on a pay-for-what-you-use basis[21].

GreenQloud along with other web hosting companies in Ireland hugely differ from their competitors in North America and Europe. This is because their data centers are mostly powered by hydroelectric and geothermal energy. This is possible because of Iceland's energy infrastructure. Also, Iceland's geographical location offers two additional ecological advantages. Firstly, the year-round cold climate in the Arctic Circle offers natural cooling. We already know that almost 50% of the energy consumed by data centers is utilized to power the various cooling devices. So data centers in and around Iceland do not need to expend energy for this purpose. Secondly, Iceland's mid-Atlantic location eliminates the need for data mirrors on both continents, hence eliminating the use of multiple data centers and the associated energy consumption.

There are a number of ways in which GreenQloud uses its Truly Green™ brand to specifically help reduce energy consumption. Their primary data centers Verne Global and Thor DC (Advania), use 100% renewable geothermal and hydroelectric energy[22]. They do not use carbon offsets to meet their goals, but maintain a public cloud that is 100% carbon neutral. They are working towards attaining the ISO 14001 environmental management certification. GreenQloud also manages its e-waste responsibly and in accordance to the standards set in its ISO 14001 compliance manual.
A big advantage of GreenQloud is that it provides its users the option of continuously monitoring the energy metrics and carbon savings. GreenQloud calculates the CO_2 emissions each user has avoided by using GreenQloud, based on the user's home origin and energy usage.

Even though GreenQloud's data centers do not have a Power Usage Effectiveness (PUE) yet, it is estimated [23] that the PUE will be under 1.2 and the Green PUE (GPUE) will be roughly equal to its PUE_X. This is most desired since, 'green' data centers will have GPUE close to PUE_X whereas 'dirty' data centers will not.

Thus we see that GreenQloud is contributing as much as possible to help reduce the carbon footprint of the ICT sector through efficient cloud computing.

6. Case Study – Google's Green Computing - Cloud Based e-mail services

Google's case study "Google's Green Computing: Efficiency at Scale" suggests that using cloud-based email is more energy efficient than running email in-house. The underlying theory that cloud computing is more energy efficient than in house hosting is pretty sound as it uses shared power and cooling resources.
For the study, Google determined the average amount of energy necessary to run email in-house at a small business with 50 email users, a medium-size business with 500 users, and a large business with 10,000 users. The study assumed that the small and medium-sized businesses would require 2 servers (a primary and a backup), whereas the large company would require 12 (10 plus 2 backups).

Combining the costs of powering and cooling the servers along with the other IT infrastructure necessary to deliver email to a user's PC, Google determined that providing email to a single user at a small business uses 175 kWh (kilowatt hours) per year (70 kWh from the two 200W servers and 105 kWh from power, cooling, and the like). A user at a midsize business would use 28.4 kWh per year (16 kWh from operating two 400W servers and 12.4 kWh from cooling and such). Finally, the large-business user would burn through approximately 7.6 kWh per year (4.7 kWh from 12 450W servers and 3.1 kWh from the non-IT resources). These figures point to the energy-efficiency gains that can be reaped through higher scalability, increased users per server, and shared power and cooling. In that vein, Google assumed at PUE (power usage effectiveness) of 2.5

for the small business, 1.8 for the medium-size business, and 1.6 for the large business. [24] [25]

These figures point to the energy-efficiency gains that can be reaped through higher scalability, increased users per server, and shared power and cooling. In that vein, Google assumed at PUE (power usage effectiveness) of 2.5 for the small business, 1.8 for the medium-size business, and 1.6 for the large business. By comparison, Google concludes that it is able to provide Gmail at an annual energy-per-user rate of less than 2.2 kWh. Google attributes this to its highly efficient servers, its server-optimized software, and a PUE of 1.16.

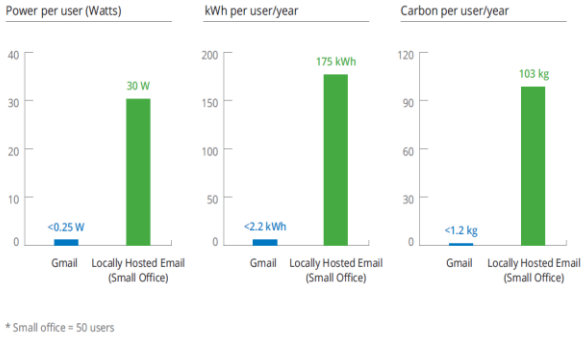

Figure-1: Locally Hosted Email vs. Gmail: Comparison of power, energy and carbon use per user/year

Further Google also claims that Gmail has shown for years that the cloud can deliver a high-quality, reliable, and useful service at a much lower energy cost than other methods. File storage, calendar, teleconferencing, voicemail, chat and document management all enjoy these energy economies. Even traditional applications such as word processing and spreadsheets may ultimately benefit if users transition from traditional PCs and laptops to lower energy devices like tablets or netbooks that store their information in the cloud. [25]

7. Case Study – Microsoft Study About Green Cloud Computing [26]

Microsoft claims that for large deployments, Microsoft's cloud solutions can reduce energy use and carbon emissions by more than 30 percent when compared to their corresponding Microsoft business applications installed on-premise.

Microsoft together with Accenture and WSP conducted a study to the saving of energy and carbon emission by cloud computing. They developed a quantitative model to calculate the energy use and carbon footprint of an organisation's IT applications (Microsoft Exchange, Sharepoint and Dynamics CRM) for both cloud and in-house deployments. This approach aligns with the assessment methodology developed by the Global e-Sustainability initiative.
The study compared the environmental impact of cloud based versus in-house IT delivery on a pre-user basis and considered three different deployment sizes - small (100 users), medium (1000 users) and large (10000 users). The analysis suggests that, on average across the different applications, typical carbon emission reductions by deployment size are:

- More than 90% for small deployments
- 60-90% for medium sized deployments
- 30-60% for large deployments

According to the report, the key factors that enable cloud computing to lower energy use and carbon emissions form IT are:

- Dynamic Provisioning: Reducing wasted computing resources through better matching of Server capacity with actual demand.
- Multi-Tenancy: Flattening relative peak loads by serving large numbers of organisations and users on shared infrastructure.
- Server Utilisation: Operating servers at higher utilisation rates.
- Data Center Efficiency: Utilising advanced data center infrastructure designs that reduce power loss through improved cooling, power conditioning etc.

8. Conclusion and Future Scope

Cloud-based computing is now developing very fast and it drastically changes the classical way of computation. Email, movies, music, television and telephone services increasingly rely on cloud computing to serve, store and transmit data. As these technologies develop and mature, efficient hardware, software, and server provisioning will continue to make the cloud the most energy efficient platform for delivering computing. Green Cloud Computing is still in its initial stage and it still we have to explore lot of things which are still not known or not explored. Cloud computing need not just remain confined to e-mail servers and private organizational clouds. It can be expanded to be used in e-commerce,

storing medical reports, fingerprint, DNA and other essential details of people, providing study materials for education, and so on. Many organizations, including Greenpeace International, claim that cloud computing does more harm than good but we have seen that with proper usage of cloud services a large amount of energy savings and reduction of carbon footprint can be achieved. We have looked into the clouds of Google Inc. and GreenQloud and found them to be quite green as compared to other clouds, like those maintained by Apple or Microsoft. Still, there is huge room for improvement and further research in this field, especially in areas like development of more efficient data servers, cooling systems, and so on. Also, efforts have to be made to shift as many users as possible to using all the varied cloud services so as to maximize the gains available from cloud computing. Thus, we conclude by saying that cloud computing is not a farce but if used efficiently can go a long way in helping to reduce carbon footprint of the ICT sector.

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Chiranjeeb Roy Chowdhury was born in Kolkata in 1992. He is a final year student of BSc. Computer Science (Hons.) at St. Xavier's College (Autonomous), Kolkata. He is a hardcore coder and has an in-depth knowledge of a plethora of programming languages, like C, C++, Java and C#. He is interested in a large number of fields in Computer Science since school level, including Cryptography, Graph Theory and Internet and .NET Technologies.

Arindam Chatterjee was born in Kolkata in 1991. He is a final year student of BSc. Computer Science (Hons.) at St. Xavier's College (Autonomous), Kolkata. He has worked with a large number of graphical, audio and image processing software. He is also an able coder, but considers image processing his primary strength.

Alap Sardar was born in Kolkata, in the year 1991. He is a final year student of BSc. Computer Science (Hons.) at St Xavier's College (Autonomous), Kolkata. Apart from being a quality coder, he also has a keen sense of music and is an expert Synthesizer player, who performs regularly both for his college and professionally elsewhere. He is currently the secretary of the Xaverian Academy of Dance and Music. This is his first publication.

Prof. Shalabh Agarwal is an Assistant Professor in the Computer Science Department. He is busy with different research projects. His primary research area is Green Computing, e-learning. He has published several papers in National and International Journals and conference proceedings.

Dr. Asoke Nath is the Associate Professor in Department of Computer Science. Apart from his teaching assignments he is involved with various research works in Cryptography, Steganography, Green Computing, E-Learning. He has presented papers and invited tutorials in different International and National conferences in India and abroad.