GREEN CLOUD COMPUTING

ACIT4100 EXAM FALL 2021

CANDIDATE NUMBER: 152

Table of Contents

1 Introduction

In August, the UN.'s climate panel released a highly anticipated and grim report on climate change. The report warns that the average global temperature will reach 1.5 degrees Celsius or even 2 degrees Celsius above pre-industrial levels in the next two decades, without "immediate, rapid and large-scale reductions in greenhouse gas emissions."(Plumer, 2021) This threshold is significant because scientists have estimated that the dangers of global warming, like deadly heatwaves, floods, and extreme weather, highly increase when it is passed. The UN. Secretary-General António Guterres called the report a "code red for humanity."(Nina Chestney, 2021)

The report comes after a series of extreme weather incidents in the world this summer. Deadly floods in several places in Europe, India, and China, heat waves that killed hundreds of people in the United States and Canada, and wildfires entirely out of control in Greece and Turkey. According to the same report, events like this are only the beginning. (Nina Chestney, 2021)

All of this may seem a little hopeless, but all efforts to combat climate change are meaningful. Even if many of these changes cannot be undone and the world doesn't reach its goals. Keeping the world from getting even 0.2 degrees warmer can make a huge difference. It can mean that lives can be saved, or places can remain habitable that wouldn't be otherwise.

Technology is often presented as the solution for climate change. That new advanced technology is what ultimately will save us in the end. But something that tends to be forgotten is how much emissions technology is responsible for. It is a paradox that technology can help reduce emissions and be seen as one of the ways to solve the climate crisis, while at the same time also contributing to making it worse.

Scientists have previously estimated that Information and communications technology, or ICT for short, is responsible for between 1.8% and 2.8% of greenhouse gas emissions. But a recent study indicates that ICT's carbon footprint is, in fact, more likely somewhere between 2.1% and 3.9% of greenhouse gas emissions. (Freitag et al., 2021). If this is correct, ICT can have a larger, or just about the same, carbon footprint as the aviation industry. This is hard to estimate accurately, but the general consensus among scientists is that the aviation industry is responsible for around 2-3% of emissions. While there is a discussion about how bad flying is for the environment, ICT usually doesn't get the same attention.

A big chunk of these emissions comes from the increasing number of data centers around the world. As cloud computing has revolutionized the tech industry, saving consumers time and money, the demand for these centers has multiplied. To function, they use an immense amount of energy, having a significant carbon footprint.

Even though technology is and has had a negative impact on the environment, it doesn't have to be like that. Some technology known as "green" technology can actually help reduce emissions. Even though technology like this cannot undo the damage that has been done to our planet, it can at least stop climate change from getting worse.

A great example is green cloud computing. Green cloud computing refers to using cloud computing in such a way that will reduce emissions and help fight climate change. This paper will provide an understanding of what green cloud computing is, how to achieve it, and what the big cloud providers are doing about it.

The remainder of the essay is organized as follows. Section two discusses the methodology. Section three defines and describes cloud computing as a concept. Section four defines green cloud computing and explores different techniques and methods to make data centers more energy-efficient. Section five is about the cloud providers, discussing what they have achieved, their goals, and critiques. The last section concludes the essay.

2 Methodology

In this section, some of the methodologies applied by the chosen research for this essay, will be presented and discussed. Most of the research articles used in this essay are either case studies, reviews, or surveys. A case study is an in-depth study on one topic and is primarily qualitative. It is an excellent way to describe and gain insight into different aspects of a research area. Case studies can also give the impression that similar studies will provide the same result. This is not the case. The problem with case studies is that they can't be generalized and don't provide statistical significance. (Lazar et al., 2017)

In the research article "Green Cloud Framework for Improving Carbon Efficiency of Clouds," a carbon aware green cloud architecture was proposed. It was later evaluated in a case study, where the focus was on LaaS providers in particular. (Garg et al., 2011). It is not guaranteed that the results can be replicated. Still, it provides a general understanding and insight into their framework.

The authors could support their assumptions even better by using three case studies in the paper "VM consolidation: A real case based on OpenStack Cloud" (Corradi et al., 2014). They wanted to show that VM consolidation can be a solution from a practical viewpoint. These case studies explored three different aspects related to power, CPU, and networking resource sharing. In this way, by using more than one case study, they can better support their results even if they don't have statistical significance.

Reviews and surveys are often used interchangeably and give an overview of studies published on a topic. They summarize and describe instead of presenting new results and experiments. Having an expert read and explain the articles can be valuable since they may see things someone less experienced and knowledgeable would miss. Therefore, this methodology requires that the researcher is educated and well-informed about the topic. In this way, the articles will not get misunderstood or misdescribed. (Palmatier et al., 2018)

The survey "Green computing approaches" (Dhaini et al., 2021) examines different green computing methods in various areas of software development. Although the article gives a good overview of the topic and links the articles together well, it doesn't seem to be a set method to find the literature. This can increase the chances of the review being biased. (Grant & Booth, 2009)

(Chaurasia et al., 2021) and (Radu, 2017) were more systematic in their approaches, by, for example, using specific keywords and research questions in their searches. Chaurasia et al. presented a systematic survey of existing energy-efficient techniques, focusing on energy-aware server consolidation, where the techniques were discussed and categorized. The most important articles were identified in each category, including open issues in the literature, which can be explored further. (Chaurasia et al., 2021). Radu provides up-to-date guidance for research done on green cloud computing. The article gives a summary of recent studies and developments and presents challenges and future research directions. (Radu, 2017)

Both of these articles have a clear outline for the methodology they wanted to use, and the searching stage was well defined. But by using so much literature and research, the quality assessment may not be as good, which may lead to bias. The author also won't be able to go as much into depth of the topics as you can with, for example, case studies. (Grant & Booth, 2009)

The authors have a great responsibility when choosing the research to focus on since some ethical dilemmas can present themselves. It is their job to identify the works that are done well and are relevant to the study in order to ensure adequate quality. The chosen research also needs to be done ethically and by someone who doesn't have unethical reasons to publish it. This can, for example, be a financial gain or strong personal beliefs that may affect the research. The fact that the author has some form of conflict of interest is not unethical in itself, but failing to inform that they do is. It is essential that the author doesn't just cherry-pick research that they agree with and that the research represents many different viewpoints. A researcher needs to recognize that everyone has a bias and how their own values may affect the interpretation. When writing review and survey articles, it is common to go through a lot of research. Each work needs to be read thoroughly, and given the energy it deserves, or misunderstandings can happen. Proper prior knowledge is critical to assess the quality of someone's work.

3 What is Cloud Computing?

To fully grasp green cloud computing, an understanding of cloud computing in itself is needed. So in this section, the focus will be on explaining what clouds have to do with technology and how this technology actually functions.

Clouds, these white fluffy, misty blobs may seem far away and unrelated to technology. And they are. In fact, Cloud computing has very little to do with real clouds. Clouds are a prevalent metaphor, which has been used a million times before in music and literature. Like having your head in the clouds, being on cloud nine, or seeing dark clouds on the horizon are common expressions being used in everyday language. Their shape-shifting nature makes them great for representing everything from being detached from reality to simply being a symbol of heaven. (Rosen, 2011)

As cloud computing has become so well used and known, the word "cloud" has managed to become its own buzzword. In the general population, it refers to somewhere mysterious, faraway, where you can store data. Maybe even somewhere that can provide access to apps on your phone. Somewhere unreachable, floating, and wireless, just like a real cloud. (Hsu, 2015) This is while the cloud's content remains unknown and is seen as too complex to understand for most people. As much as the word "cloud" is used today, very few actually understand what it is and the technology behind it.

Metaphors are a great way to explain something and can make a concept easier to understand. But they will always be incomplete and present something partially. This is also the case with cloud computing. In 2012, a famous survey in America showed that 50% of the respondents thought bad weather could interfere with cloud computing. (Yarow, 2012) This is despite 97% of them using it themselves, most of them without knowing. Even though this is a couple of years ago, it shows that this metaphor can be more misleading than helpful.

The cloud metaphor originates from when engineers back in the day would map out all the components of computer networks in blobs. They were illustrated by circles, lines, and boxes, which together ended up resembling clouds. (Croker, 2020) But the details inside these blobs or clouds didn't really matter for ordinary people. They were seen as too complicated. Therefore, the cloud became this black box where intricacy was hidden inside and forgotten. But cloud computing is not as complex as people might think.

The United States National Institute of Standards and Technology (NIST) defines cloud computing as:

"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."

An easy way to explain it could be to imagine it as a restaurant. (S., 2020) When preparing food at home, you are responsible for everything. You need to have all the necessary kitchen supplies and ingredients yourself, while also having the skills to prepare the food. You will need to know how many people you will be cooking for and get the right amount of ingredients. This is so you don't make too little, so your guests will stay hungry, or too much food that you will have to throw away in the end. In addition to all this, you will be responsible for cooking, setting it up, and doing the cleaning afterward.

This is very similar to how it was for internet providers back in the day. You had to buy or rent all the computer hardware while also predicting how many users you would get to ensure that the servers could handle it. This is all in addition to being responsible for all the maintenance work. However, with cloud computing, it's the opposite. It can be compared to going to a restaurant. They will have enough kitchen supplies and tableware and enough food for bigger and smaller groups of people. It is more expensive than cooking at home, but you only pay for what you eat. They will also offer more exciting and more challenging dishes that you maybe won't be able to make at home so easily. This is just how it is with the big cloud computing providers like Google Cloud, AWS, or Azure. Just like the restaurant, they have a lot of power, offer newer and more complex technology, and you only pay for what you use. And you don't need to perform any cleaning or maintenance work ever. Everything will just work without you having to think about it.

So, to put it simply, it's the delivery of different IT services over the internet. This means that the consumer no longer needs as much physical infrastructure, which is now moved to remote data centers controlled by cloud computing providers. (Garg et al., 2011; Jayalath et al., 2019) The user will not have to maintain the resources while the services are provided pay per use. This dramatically reduces the cost and time for the companies. (Maryam et al., 2018; Wadhwa & Verma, 2014)

As explained earlier, metaphors and analogies are a great way to understand a concept but will always leave things out. Therefore, attempting to open the black box that the cloud lives inside can be needed. According to the National Institute of Standards and Technology definition mentioned earlier, cloud computing has five essential characteristics: On-demand self-service, shared resource pooling, rapid elasticity, measured service, and broad network access. Although these characteristics were explored in the analogy earlier, a more specific and technological explanation can provide an even better understanding.

On-demand self-service: On-demand self-service refers to being able to adjust and request computer resources with as little help from another human as possible. (Croker, 2020)

Shared resource pooling: This refers to cloud shared infrastructure, which is used by different people across the world. The users will not know where the resources come from or who they are sharing them with. (Garg & Buyya, 2012)

Rapid elasticity: Rapid elasticity means the computer resources can efficiently be allocated and adjusted according to the users' needs. (Croker, 2020; Garg & Buyya, 2012)

Measured service: This referes to that the customers only pay for what they use. The cloud providers typically measure the bill by the amount of computing power, bandwidth and storage used during a certain period. (Croker, 2020)

Broad Network Access: Broad network access means that the cloud resources can be used through various networks or a wide variety of computing devices. In other words, the user, in most cases, will get access, regardless of which device they are using or the operating system. (Croker, 2020)

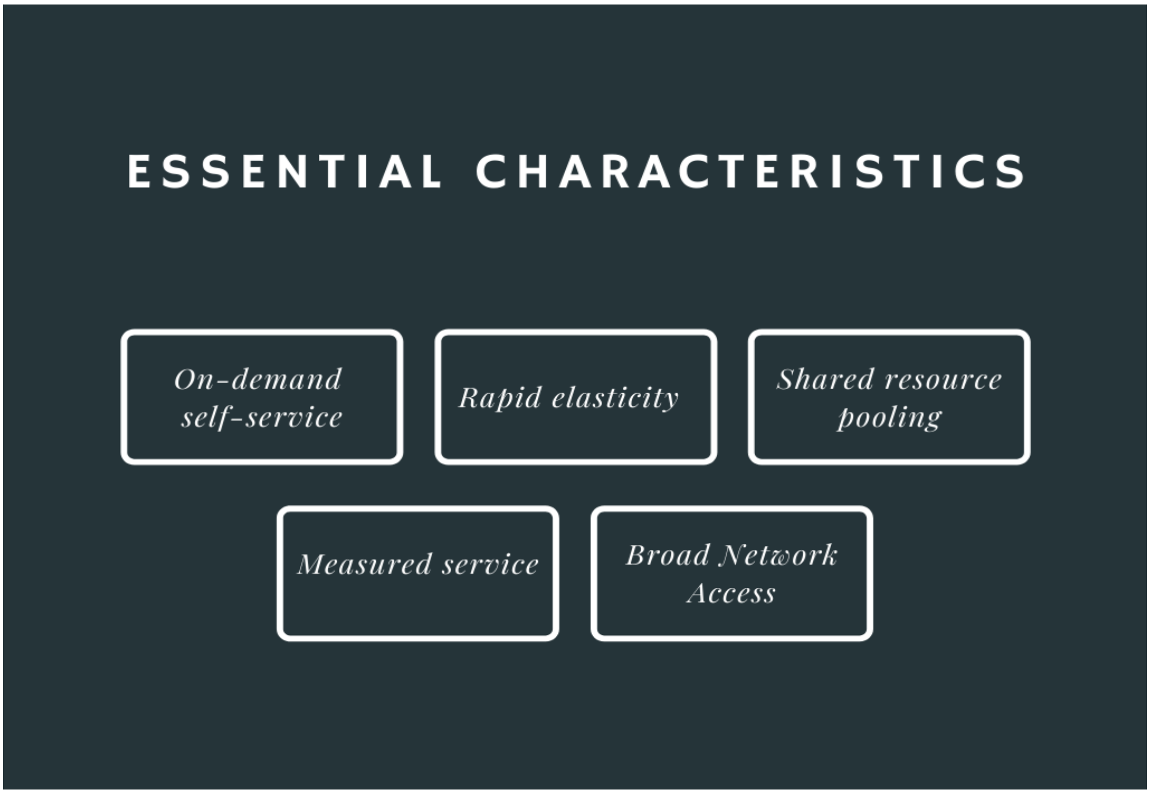

Figure 1 shows NIST's essential characteristics of cloud computing.

3.1 Service Models

Another typical way to describe the cloud is through three different service models and four deployment models. The service models are Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS). Each of these models offers a different set of services to end-users. (Croker, 2020; Garg & Buyya, 2012)

Infrastructure as a service (IaaS): This service provides infrastructure products through the internet, like virtual machines, storage, and clusters. (Garg & Buyya, 2012) So instead of buying hardware, users can pay for IaaS on demand. This means that maintenance or operating costs will be low, saving the users time and money. (Jayalath et al., 2019). The user can typically decide the operating system they would like to use, and how much speed the computer they rent should have. The main benefits are that the users can just use the infrastructure they want and extend this as needed. They can also stop when they want to and only pay for what they use. (Croker, 2020; Maryam et al., 2018).

Platform as a Service (PaaS): PaaS gives its users access to an operating system without needing to provide access to the computer's hardware. (Croker, 2020) This is a service used mainly by developers and programmers. This is because PaaS allows the user to run and manage their own applications without maintaining and building the corresponding platform or infrastructure. (Garg & Buyya, 2012) For example, can an application-developer use PaaS to host a virtual machine to test something without needing access to the computer hosting the machine. (Croker, 2020). They also won't need to worry about hardware maintenance or software updates since the provider is responsible for this. (Garg & Buyya, 2012)

Software as a Service (SaaS): This is probably the easiest one to understand out of the three. Saas gives the users the possibility of buying applications over the internet. They will not need to worry about the hardware, operating system, maintenance, installation, or support. The provider will be responsible for this. (Croker, 2020; Jayalath et al., 2019)

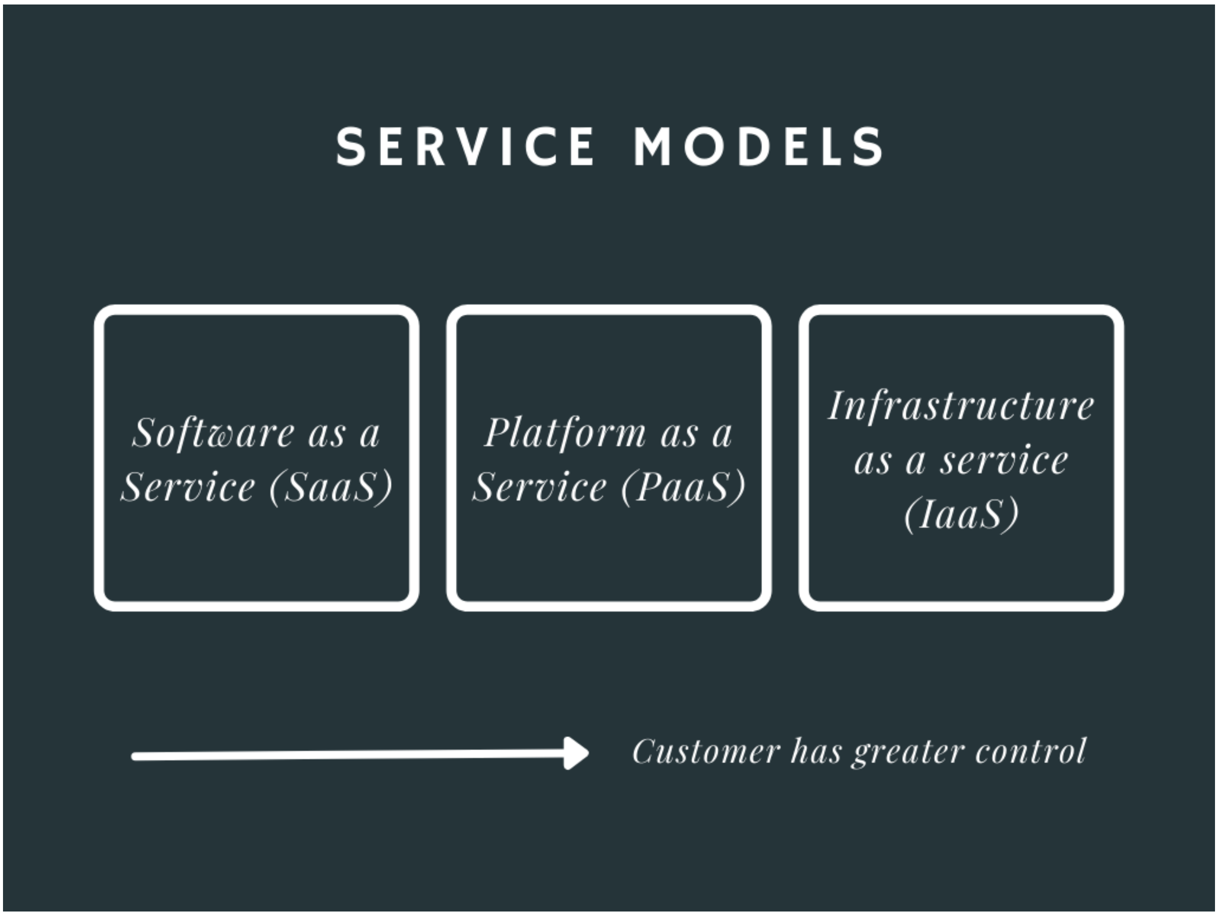

Figure 2 shows the service models sorted by which gives the customer the greatest control. Inspired by (Winkler, 2011).

3.2 Deployment Models

Another way to talk about cloud computing is through deployment models. These models identify cloud environments based on where it is located, who has access, and the cloud's purpose. There are four different ones: private, community, public, and hybrid.

Public clouds Public cloud is the most common deployment model and provides services that everyone can access. (Garg & Buyya, 2012; Maryam et al., 2018) A public Cloud can offer any of the three services explained above: IaaS, PaaS, and SaaS.

Private clouds: The opposite of a public cloud is a private cloud. These are not meant to be accessed by the public. (Jayalath et al., 2019) These are limited to a particular group or organization and provide the opportunity to specialize the cloud to their specific needs. Therefore the model offers more control and flexibility than the public model (Garg & Buyya, 2012).

Community cloud: This model allows access to groups of specific organizations with shared concerns. It's often managed by a third party or a combination of organizations in the community (Jayalath et al., 2019). They are more private and limited than a public system. (Croker, 2020)

Hybrid cloud: The hybrid cloud model is the mixture of two or more of the other models. (Jayalath et al., 2019; Maryam et al., 2018) Here you can utilize the best part about each of the other models. Non-critical data can be processed in the public cloud, which is faster, while they still can use the private for the data they want to protect. (Garg & Buyya, 2012)

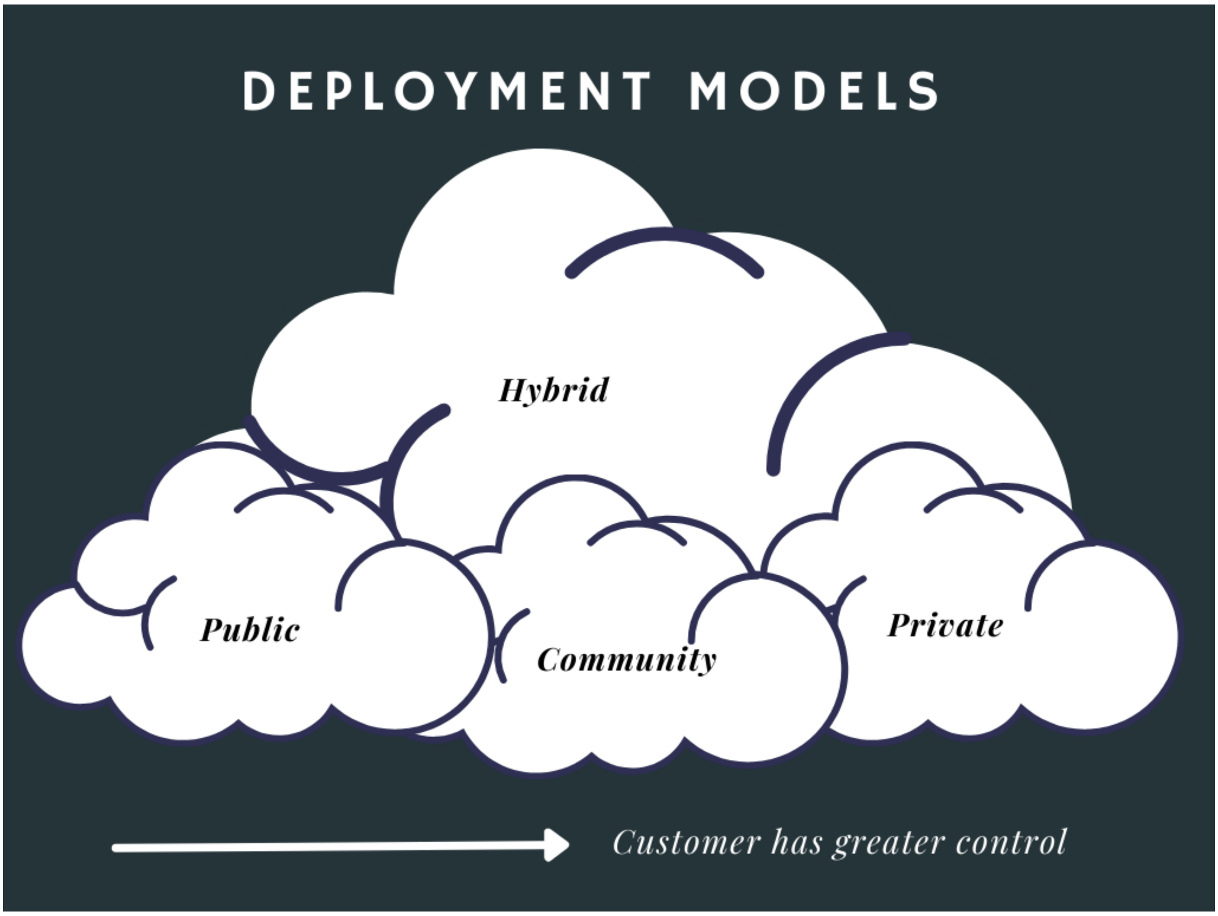

Figure 3 shows the deployment models sorted by which gives the customer the greatest control. Inspired by (Winkler, 2011)

4 Green Cloud Computing

There is no doubt that Cloud computing has revolutionized the tech industry, but that doesn't mean that it doesn't have disadvantages. The cloud exists both as a digital concept and as a physical object. Physically the cloud lives in data centers spread across the world. The cloud is already greener compared to traditional data centers, but with the rapid growth of the industry, energy consumption and carbon emissions have increased just as much. (Jayalath et al., 2019) Now that we have gained an understanding of how the cloud functions, we can better understand how to make it green. This is what this section of the paper will focus on.

Figuring out data centers' exact carbon footprint methodologically is not easy. Even though there is a lot of research on the topic, there is still a need for more in-depth studies. Also, the studies use different metrics and different ways to get their numbers, making the results differ. But one report In 2010 estimated that global electricity usage by data centers alone was somewhere between 1.1% and 1.5% (Dayarathna et al., 2015). Considering how much the industry has grown since then, it is good reason to believe this is relatively higher today.

Cloud computing’s energy consumption is not the only negative effect. Another one is electronic waste. (Cholli, 2021) Equipment often gets replaced as quickly as new and better technology gets on the market. Some may also use cloud computing to mine cryptocurrencies, which isn’t exactly environmentally friendly either. In 2018, a study reported that the Bitcoin industry alone could produce enough CO_2 to result in a 2 degrees Celsius warming by 2050. (Mora et al., 2018)

Hiding the cloud inside a black box also has consequences for energy consumption. Like how the users can't see how it works, they also don't know how damaging it can be to the climate. This may be why cloud computing's environmental impact doesn't get discussed as much compared to other industries. Even though its carbon footprint is as significant as it is.
But cloud computing can actually help reduce emissions, and green cloud computing is just that. Quite simply, it means using cloud computing to reduce emissions and minimize its carbon footprint. (Cholli, 2021) So how can we do that? An excellent way to start is with the heart of cloud computing, the data centers.

4.1 What is a Data Center?

So firstly, what is a data center?

If you ever get the chance to visit one, you may get underwhelmed by the outside. They are typically dull, non-descript buildings designed not to get noticed. A stark contrast to all the power it conceals inside. This is done with intention, as these buildings are highly protected and tend to have loads of security.

No data center is the same, and they all vary in size and in the equipment used. Usually, they include some compute components like servers, components that provide storage, and network components like routers, switches, and firewalls. They also often have support infrastructures like cooling systems, power subsystems, uninterruptible power supplies (UPS), and ventilation. (Cisco, 2021; Garg & Buyya, 2012). Because of all the equipment, data centers need a lot of energy to function. Even though research and studies have highlighted this problem and there have been following attempts to adopt green cloud computing, power consumption is sadly still rising. (Jeba et al., 2021) This is not mainly because of lack of action but because of the steadily growing demand, making it hard for the cloud providers to keep up.

4.2 Techniques and Methods

Thankfully, it is easier to make these big data centers “greener” than the individual infrastructure they have replaced. There are several methods and ways to achieve energy efficiency. Significant factors are the data center’s physical design and how it is built. The entire infrastructure must be designed for maximum energy efficiency and for as little carbon emissions as possible. (Radu, 2017) This means that the buildings should be made with low-emission materials, while the data center is mainly powered by clean energy, and the power usage is minimized. Another way to improve energy efficiency is to use virtualization techniques to better manage the resources.

In order to ensure proper energy optimization in a data center, it can be helpful to estimate how much each individual component consumes. The amount of energy consumed will depend on the design of the data center as well as the efficiency of the equipment. Therefore, this is something that will differ from data center to data center. (Dayarathna et al., 2015)

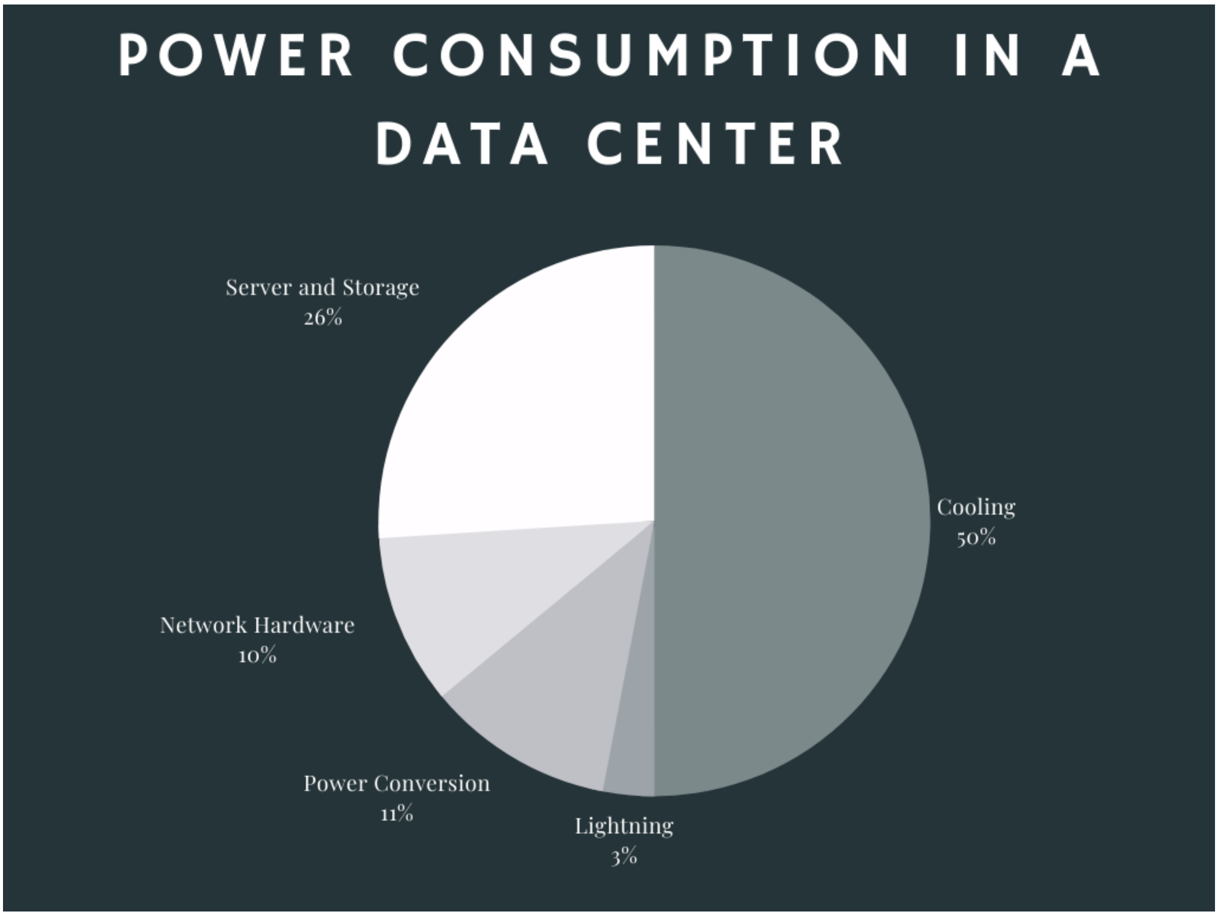

Figure 4 is a pie chart that illustrates the power consumption in a typical data center. Data from (Group, 2007)

The chart above illustrates the equipment typically used in data centers and how much energy each device uses. This is based on statistics published by the Infotech group (Group, 2007). The largest energy consumer in a typical data center is the cooling infrastructure, with 50% of the power. This makes up double that of the servers and storage systems usage. (Dayarathna et al., 2015) This happens because they are often not designed well and are ineffective, using more energy than needed. In order to improve energy efficiency in data centers, each of these devices needs to be designed and used efficiently. Especially the cooling system is a considerable energy thief, which needs to be dealt with.

4.2.1 Cooling Systems

If you ever get the chance to go inside a data center, it's probably wise to bring noise-canceling headphones and a warm jacket. Visually, you will first notice all the blinking lights flashing in different colors, showing how the servers communicate with each other in red, yellow, and blue. But the most significant part of the experience is the noise and temperature.

The sound can be described as a constant humming in the background, getting annoying for the people working there over time. It comes from all the systems doing their jobs, the fans, the cooling, heating, and other systems working together to create the cloud's magic. The data centers cooling system will also affect the temperature, giving the data center a quite particular atmosphere. When walking further inside the center, in between the racks of equipment, the air will alternate between being warm and pretty cold. This creates areas in the center that are freezing cold to be in, while others make you sweat because of the heat.

As explained earlier, these cooling systems typically consume the most amount of energy. Therefore, improving these systems is essential for ensuring energy efficiency. When it comes to the cooling systems, it is not just the software and hardware that matters, but also the way the building and room are designed. Typically, a data center has a hot aisle/cold aisle layout design to manage airflow. (Gupta et al., 2011) Though this is something that differs from data center to data center. But typically, this means lining up server racks front to front and back-to-back. In that way, the front, which takes in cool air, doesn't mix with the back that lets out hot air. This is why some areas of the data center stay cold, and some are hot. The released hot air is then removed through the vents in the ceiling into the CRAC (computer room air conditioner). Usually, this also includes a raised floor, low ceilings, and tiles made of holes. This makes sure that the air from the CRAC can pass through the raised floor. (Gupta et al., 2011)

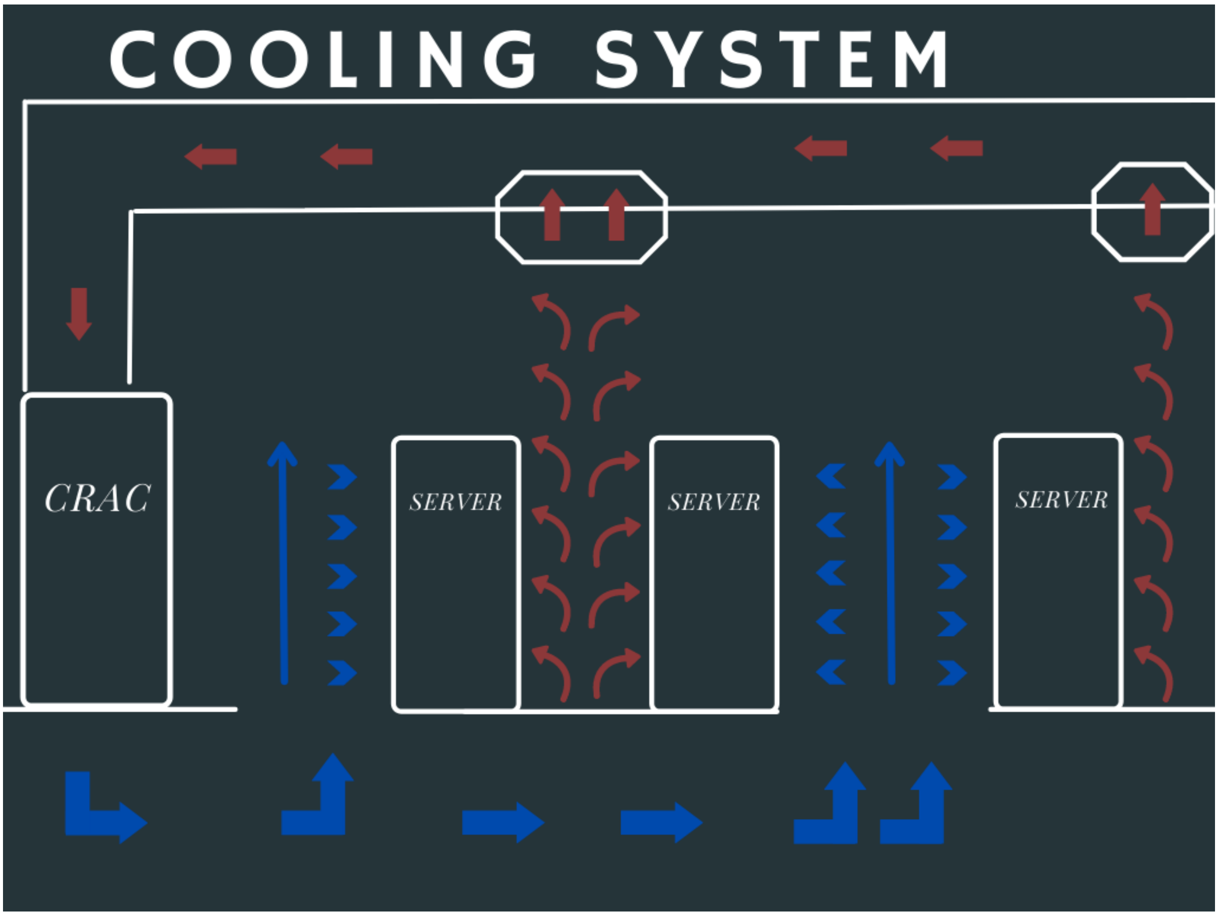

Figure 5 shows a typical cooling system with a hot/cold layout design and a raised floor. The blue arrows illustrate the cold air, and the red ones represent the hot air. Inspired by (Priyadumkol & Kittichaikarn, 2014)

There is also newer technology that cools down the data center with the help of liquid. Google, for example, uses the ocean to cool down one of their data centers in Finland. Here they deliver the cold water through pipes to cool down the hot equipment. (Cholli, 2021).

The location can also help with cooling. Choosing geographical areas for data centers with outside temperatures less than 13 ◦C for at least four months of the year can help. (Radu, 2017) This, for example, provides the opportunity to use a technique called economizer cooling, which is used in modern data centers. This method uses cold air from the outside of the center to cool down the hot equipment. (Cholli, 2021). Microsoft has a data center in Ireland that uses this exact technique. Since the climate is cool enough, they can use air cooling to cool down the data center. A system like this has the ability to lower energy requirements by up to 60%. (Naji et al., 2019). Microsoft has also tried more "out-of-the-box" solutions, like locating the servers underwater to keep them cool. (Cellan-Jones, 2020) Additionally, locating the servers in places where renewable energy from, for example, solar or wind, is easily available, can also help.

Lastly, the heat removed by the cooling system can also be utilized. This can be a valuable resource but is rarely used for anything. Google, for example, is planning to build one of the world's biggest data centers in Skien. (Richard Aune, 2021) They will use water from Lake Norsjø to cool down the center and release the water back into the lake when the cooling effects stop. This water could theoretically have powered an entire city, but now it's just going to waste.

4.2.2 Virtualization Techniques

Virtualization is simply to create virtual versions of real things. For example, creating a virtual desktop, operating system, file, server, storage, or network. (Jayalath et al., 2019) As explained earlier, cloud computing is the delivery of services over the internet, where virtualization plays a significant role. (Rao & Babu, 2017). A central part of early cloud development was the creation of virtual machines or VMs. A virtual machine is a machine that can exist on its own inside a computer. (Croker, 2020) In the early 2000s, developments in virtualization provided the opportunity to create robust VMs, which made it possible to run more than one operating system on one physical machine (Gill & Sharma, 2015). This was really important for the development of the cloud, and it wouldn't be what it is today without it.

Typically, virtualization tends to be used as a way to share the physical computer's capacity. This is done by sharing the resources between the operating systems. (Naji et al., 2019) Therefore, virtualization techniques can be used for improving resource management and bettering energy efficiency in the cloud. It can help decrease the amount of hardware in use, help utilize resources better, and reduce operating costs. (Cholli, 2021)

One way virtualization can help utilize resources better is by minimizing the number of servers in use. (Mandal et al., 2020) This can be done by a technique called VM consolidation. Here the main objective is to run the VMs on as few servers as possible. In this way, the workload will get more concentrated, and unneeded servers can get turned off. (Corradi et al., 2014) This works by migrating VMs from underutilized servers, so servers can get properly "filled up" by VMs and be used at total capacity. VMs will also migrate the other way around when the server gets too full. (Mandal et al., 2020) This can be done by several different algorithms. (Naji et al., 2019)

There are also other forms of VM management, like dynamic scheduling of VMs. One example is power-aware scheduling, where VM workloads can be scheduled to decrease the server's power (Naji et al., 2019). Another is thermal aware management techniques, where the jobs are scheduled based on thermal aspects to reduce the heat in the data center. (Radu, 2017)

4.2.3 Electronic Waste

One crucial point in green cloud computing and in green tech, in general, is the reduction of e-waste. (Radu, 2017) E-waste has become a massive problem for the world with the evolution of technology. As explained earlier, the responsibility for upgrading and maintaining the hardware falls on the cloud providers and not the consumer. Unfortunately, it is common for equipment to quickly get replaced as soon as more efficient technology gets on the market. In 2014, a total of 41.8 million metric tonnes was generated worldwide. (Debnath et al., 2016)

But in some ways, cloud computing can help with e-waste. The customers, for example, will have a lot less infrastructure and equipment to worry about. This equipment will also, in turn, be used more efficiently by the cloud provider. But even though it can be argued that cloud computing minimizes e-waste, it is still a massive problem for the industry. (Radu, 2017)

Fortunately, techniques for recycling e-waste do exist and can be used. This helps to use the equipment for new things, rather than have it get thrown away. (Cholli, 2021) This is important because most e-waste doesn't get recycled and usually ends up in household waste. (Debnath et al., 2016) So to solve this issue, there needs to be more awareness among the individual consumers. As well as solutions by companies, which makes it easier to recycle. It is much easier to focus on the big data centers than the smaller private infrastructure that came before them. These data centers are also run by companies that are a part of the world's biggest and most lucrative. This makes them very capable of creating well-thought-out solutions for dealing with e-waste.

5 The Cloud Providers

Google, Amazon, and Microsoft are by far the biggest cloud providers in the industry. With Amazon’s AWS being at the top with 32% of the market share, Microsoft’s Azure second with 20%, and Google cloud third with 9%.(Richter, 2021). This section looks at how the vendors are adopting green cloud computing. Followed by their goals for the future and criticism they have faced.

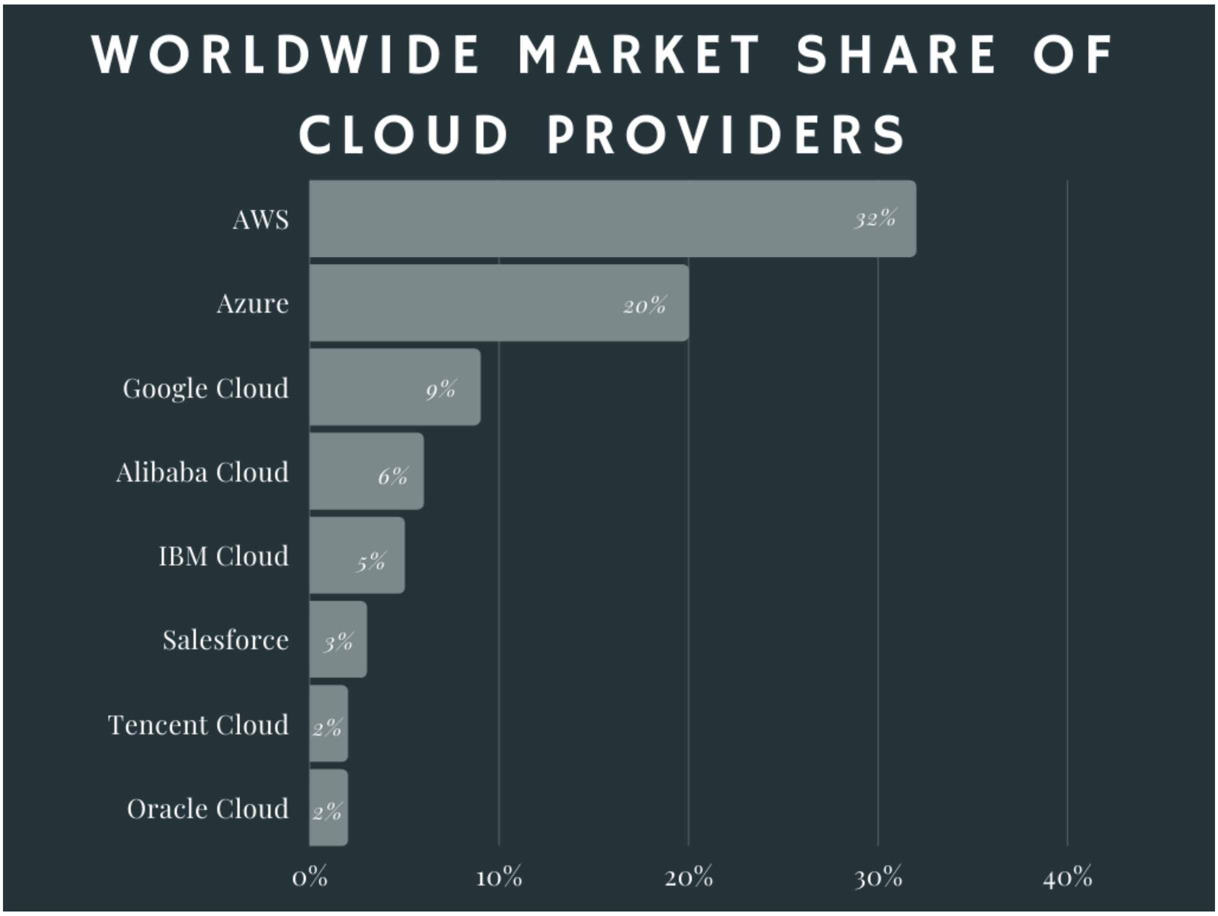

Figure 6 shows the leading cloud providers worldwide market share. Inspired by (Richter, 2021)

All of these companies want to present themselves as environmentally friendly, but are they really? They all have their own plans to minimize their carbon footprints, some more extensive than others, which is followed to different degrees. But as they are painting this picture of them becoming “greener,” all of the vendors hypocritically enough have connections to the oil and gas sector. Wanting to help them quickly and cheaply extract even more oil and gas. (Tim Donaghy, 2020)

5.1 Amazon

Microsoft Amazon Web Services (AWS), the cloud platform provided by Amazon, is one of the leading cloud vendors, with a full 32% of the market share. (Richter, 2021) By 2025 they plan to only use renewable energy in their data centers and are continuously working to make their infrastructure more energy efficient. (Amazon, 2021b) In 2019, Amazon's CEO Jeff Bezos announced that Amazon is co-funding the “climate pledge.” (Amazon, 2019a) Where they pledge to ultimately reduce its emissions to zero by 2040. He has also made a $10 billion fund to address climate change. (Amazon, 2019b).

Amazon, unfortunately, has a history of hiding its carbon footprint from the public. They have been heavily criticized for this by Greenpeace, which considers them the least transparent company out of the three, giving them an F rating. (Stackl, 2020) Although they now release annual reports about their emissions, the first one was as late as 2019. This report was also only published after extensive pressure from consumers and investors.

At the same time, as they are trying to become more environmentally friendly, they also have strong ties to the oil and gas industry. So all these promises come across as a little hypocritical when they heavily advertise AWS as a great way to extract more oil and improve drilling. (Amazon, 2020) They have now updated their websites targeting the energy sector instead of oil and gas after their contracts with the latter have been more known. (Amazon, 2021a; Tim Donaghy, 2020) The emissions that result from these contracts are not considered a part of their reported carbon footprint, and in order to actually become a green company, they have to end these partnerships.

Company	*Contract focus*
GE Oil & Gas	*Pipelines*
Willbros	*Pipelines and Storage*
SEAOIL	*Shipping and Storage*
BP	*Corporate Operations*

Figure 7 shows an overview of Amazon's connections with the oil industry from the Greenpeace report. (Tim Donaghy, 2020)

5.2 Microsoft

Microsoft has also made a lot of promises to become green. Their goal is to completely remove their data center's carbon footprint and become carbon negative by 2030. They are also working on removing all the emissions they have ever emitted since the company was founded, by 2050. This includes using only 100% renewable energy by 2025, and stopping their usage of renewable energy credits. (Smith, 2020) They did actually manage to become completely carbon neutral after 2012, and have only used renewable energy since 2014. (Jayalath et al., 2019) But this is only without counting their usage of energy credits, which they now are planning to stop using, being one of the few companies to do so.

But something that is excluded from their carbon footprint equation, is their connections to the oil industry. These partnerships with oil companies, sparked so much anger among many Microsoft employees that they joined employees in Amazon and Google in the 2019 climate strike. (MSWorkers, 2019). Hypocritically enough, they also decided to sponsor the International

Petroleum Technology conference in Saudi Arabia, the exact same week they announced that they are becoming carbon negative. (Tim Donaghy, 2020)

Company	*Contract focus*
Schlumberger	*Subsurface modeling, drilling*
CGG	*Subsurface modeling*
XTO - ExxonMobil	*Drilling, Pipelines*
Plains Midstream Canada (PMC)	*Pipelines*
Seadrill	*Drilling*
Chevron	*Exploration, Midstream logistics, Well management*

Figure 8 shows an overview of Microsoft's connections with the oil industry from the Greenpeace report. (Tim Donaghy, 2020)

5.3 Google

According to a Greenpeace report, Google is the greenest option of all the cloud providers. (Cook et al., 2017) Since 2017, they have only used renewable energy for all their operations and data centers and were one of the first big companies to do so. Google also claims to be the "largest corporate buyer of renewable energy in the world," by matching their annual electricity consumption with renewable energy for four consecutive years. (Hölzle, 2021; Pichai, 2019)

Although we are using more computing power than ever, Google has managed to increase its power seven times in five years while using the same amount of electrical power. (Hölzle, 2021) They do this with well-designed data centers, making them sustainable and efficient, powered by renewable energy. (Jayalath et al., 2019). Using many of the techniques explored in this essay like smart cooling techniques and proper power management. An example is a machine learning technique that can predict how different factors will affect energy consumption, adjusting the data centers cooling system accordingly. In this way, always ensuring minimal energy consumption. (Amanda Gaspari, 2018)

The goal that google now is working toward is to run entirely on carbon-free energy everywhere by 2030. (Pichai, 2020). This means to stop all emissions from their operations altogether instead of compensating for it. Compared to Amazon, Google is very open and transparent about their energy use, publishing a highly detailed environmental report every year. And looking at the numbers from 2020, they seem to be well on the way to achieving their 2030 goal. (Google, 2020)

Company	*Contract focus*
Chevron	*Subsurface modeling*
Total	*Subsurface modeling*
Schlumberger	*Subsurface modeling*
Cognite + Aker	*Drilling*

Figure 9 shows an overview of Google's connections with the oil industry from the Greenpeace report. (Tim Donaghy, 2020)

5.4 Comparison

After being called out by the Greenpeace report detailing the big cloud providers' connections to the oil and gas sector, they appear to slowly decrease this connection, unlike Microsoft and Amazon. (Tim Donaghy, 2020) They stated that they will no longer build custom AI tools like AI/ML algorithms to help extract oil faster and easier. However, Google will still commit to the contracts they already have. (Sandler, 2020) This is something that they still need to address as it has a highly negative impact on the environment.

	Amazon	*Google*	*Microsoft*
Energy Transparency	**F**	**B**	**B**
Renewable Energy Commitment	**D**	**A**	**B**
Energy Efficiency	**C**	**A**	**C**
Renewable Procurement	**C**	**A**	**B**
Advocacy	**B**	**A**	**B**
Final Grade	**C**	**A**	**B**

Figure 10 Illustrates how Greenpeace in 2017 gave the vendors a rating on their energy transparency, commitment to using renewables, energy efficiency, renewable energy procurement, and energy advocacy. (Cook et al., 2017)

	Amazon	*Google*	*Microsoft*
Natural Gas	*24%*	*14%*	*23%*
Coal	*30%*	*15%*	*31%*
Nuclear	*26%*	*10%*	*10%*
Clean energy index	*17%*	*56%*	*32%*

Figure 11 presents how Greenpeace estimated the vendors' clean energy usage. (Cook et al., 2017)

All the cloud vendors have made some effort in reducing their climate footprint, although some have done a better job than others. The tables above illustrate the results from the Greenpeace report in 2017, comparing the cloud providers with each other. If these companies are fully serious about fulfilling their climate goals, it is essential that they stop supporting the growth of new oil and gas extraction.

5.5 Responsibility

The cloud providers and technologists have an exceptionable amount of power. Being the only ones that genuinely can see inside the black box gives them great responsibility. The technology sector is also highly unregulated compared to other industries. It is mainly controlled by the same people earning massive profits from it. This is highly problematic. Especially when it comes to the climate, which has such a significant impact on the world. This is not something they should decide. There need to be laws that force these companies to be more transparent with their carbon footprints. It is also essential that unsustainable practices get politically regulated.

Often is the main focus for technologists just making a good product and selling that product well. The focus on profit is problematic when they work with such complicated ethical questions. This provides them with great responsibility, and accordingly, they should be held more accountable. Something the pandemic has shown us is how essential governments and governance are. While science and technology have been one of the most significant factors in getting us out of the crisis by making and producing vaccines. We wouldn't have been able to get anywhere without good political leadership. One of the only driving forces for change in the industry is pressure from the consumers. This is something that governments need to do more about.

Greenwashing among the vendors is also a big problem. Greenwashing refers to expressing faux concerns about the climate to easier sell more products and services. (Cambridge Dictionary) This, unfortunately, is a widely used strategy today because it is more profitable to change public perception than to make reforms. The vendors present themselves as more environmentally friendly than they are while just doing the bare minimum.

A great example is the vendors' controversial collaborations with the oil and gas industry discussed earlier. (Tim Donaghy, 2020) This highly contradicts how they present themselves as companies that focus on ending climate change and being environmentally friendly. In 2019, thousands of Amazon workers, along with workers from Google and Microsoft had a climate walkout, demanding Amazon to drop fossil fuel contracts, decrease emissions to zero, and stop funding climate change deniers. (Ghaffary, 2019) Amazon responded by trying to silence the protesters, and at least three workers received termination threats. (Greene, 2020; Paul, 2020) That doesn’t exactly sound like a company genuinely wanting to mitigate climate change and make a difference.

Altogether these big tech companies need to do more. Taking into account the wealth and the power they have in the world, they are not doing enough. Especially when considering the damage they have caused and the negative impact they've had on the environment alone.

6 Conclusion

The white fluffy metaphor of the cloud may still be a little abstract, but its impact on the environment is solid and significant. Particularly because of the covid-19 pandemic, the use of technology has increased and forced its way into our lives. This, in turn, has resulted in more energy consumption and more data centers, all the while a lot of the energy that ICT and cloud computing consume is wasted. By using energy-saving methods like power management and virtualization techniques, in addition to optimal cooling systems, the power can be used efficiently and adequately. Cloud computing can even result in less e-waste generated by consumers, but this will depend on the providers delivering the services.

The responsibility to make green cloud computing a reality lies on the big cloud providers and not with individuals. These companies need to switch entirely over to renewable energy and improve the energy efficiency in their data centers. They must invest in new green technology and be transparent about their own carbon footprint. If they don’t do this, they should be held accountable for the damage that they are doing to our planet. It needs to be acknowledged that technology isn’t just the solution for climate change but also something that could worsen it. It is the only way we will be able to transition to a green future with the help of technology.

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