Cloud Computing Strategies and Approaches for Better Energy Efficiency and Environmental Impact

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Abstract

Cloud computing is one of the major IT and networking innovations that started in 2006; since then, a significant part of tech companies and users have adopted the cloud computing approach as it provides efficient networking and on-demand services in addition to the high scalability and flexibility that the cloud computing can offer to its users. However, the increasing demand for cloud computing has resulted in a high energy consumption rate and higher CO2 emissions. This paper will analyze and explore the adverse effects of cloud computing on the environment and climate change based on the increased energy needed to operate cloud services around the globe. The paper will also analyze the possible strategies and techniques as alternative solutions to minimize energy consumption and CO2 footprints associated with cloud services to maintain environmental suitability through the green cloud computing approach. A survey was conducted targeting 65 individuals of different backgrounds to assess and measure public awareness regarding the environmental impact of cloud computing; the survey findings showed a need for building communities and public awareness in this regard, as a considerable number of responders were not aware of the impact and relation of cloud computing on the increased energy consumptions and carbon emissions.

Keywords- Energy consumption, Environmental sustainability, Cloud computing, Green cloud computing,

I. INTRODUCTION

The concept of cloud computing revolves around providing on-demand computation and networking services for users and companies; many services can be provided to cloud computing users, including but not limited to date storage, networking, and switching. Information and computer programs are kept on distant servers, enabling users access from any location with an internet connection. This eliminates the necessity for cloud users to be burdened by the management and costs of having physical on-site IT infrastructure by replacing them with cloud and internet-based infrastructure pay, paying the cloud providers for what they use, only allowing users to take advantage of the knowledge, capabilities, and adaptability of a cloud service provider. Cloud computing enables users to access and utilize scalable infrastructure and services as needed; this allows users to store, access, and share large amounts of information in the cloud. Additionally, cloud computing provides organizations with significant computing power to handle the processing of vast amounts of data generated daily [1].

Since 2006, when Amazon first launched its Elastic Compute Cloud (EC2), there has been an increasing demand for cloud services. In 2023, 94% of all businesses and companies worldwide were using at least one cloud computing service, which was a 14% increase in usage and adoption of cloud services compared to 2020 [2].

Cloud data centers need continuous electricity to operate their function; like any commuter, data centers generate much heat, which means that they need continuous cooling systems to reduce the heat generated. The increasing adoption of cloud computing means more energy is required to accommodate the associated operation and cooling systems, resulting in a high carbon footprint that hurts the environment. Data centers require a substantial amount of energy to deliver their services, escalating CO2 emissions. Data centers alone are projected to significantly increase energy usage, from 200 TWh in 2016 to 2967 TWh in 2030 [3]. This paper will explore the environmental effect of cloud computing and how it can be mitigated and reduced by following green strategies and approaches that ensure environmental sustainability.

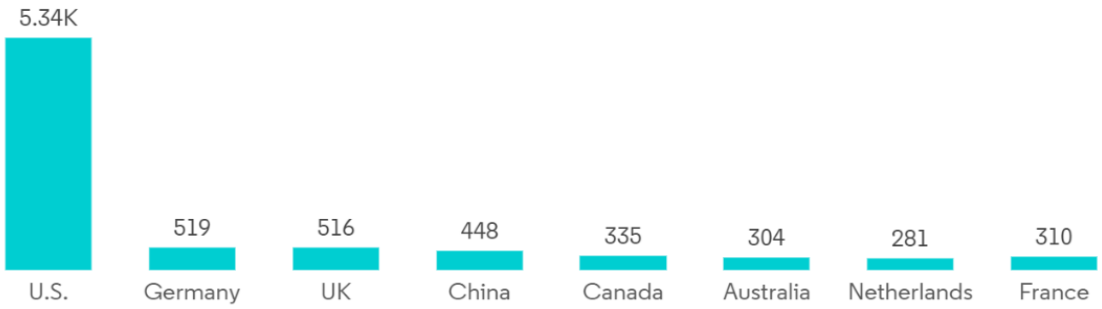

Figure 1. Number of data center around the world as of July 2023. Source [4]

II. Literature REVIEW:

Cloud computing has increasingly adopted as it offers users the ability to store and process their data using services and resources like servers, software, databases, and monitoring from remote locations with minimal management needed by the users [5]. In his article [6] mentions that the increased demand for cloud computing services will make around 200 ZB of data to be stored in the clouds by 2025, which needs a lot of energy and services to accommodate such data; around %3 of the global energy consumption is used by cloud data center around the world. Data centers of cloud consumption contribute to around %2 of global CO2 emissions, given their high energy consumption rates [7]. As cloud traffic increases, there is a corresponding increase in network energy usage. According to [8], there is an annual growth of 10%-12% related to the energy consumption of data centers. This issue must be addressed if we are to ensure sustainability. Due to the significant energy consumption of data centers, it is necessary to enhance energy efficiency at both the architectural and service levels [9]. Data centers consume the highest levels of energy through computing and cooling processes. Therefore, efficient energy usage in data centers can be achieved by coordinating several components, as these centers currently lack a unified framework to govern their operations. In their paper, [10] suggests an innovative methodology to address the power consumption issue called GENiC, which works on the idea of integrated energy systems that include data centers, cooling, heat recovery, and control in a coordinated manner to minimize the energy consumption rate.

In their article, [11] suggested a few approaches that can minimize energy consumption, which include an improved design of the software levels (OS, compilers, and algorithms) through a deep analysis of the software application behavior and responses, such as data, and analysis can be used to reduce the redesigned software that has better performance and ensure environmental sustainability. Power-aware virtual machine (VM) deployment strategies and virtual machine (VM) migration approaches have been identified to be highly efficient in mitigating the high consumption of energy in cloud structures [12].

Recent research published [13] suggested a new selection policy for power-aware virtual machines that can help reduce energy consumption based on a predetermined threshold. According to [14], almost 40% of the total energy consumed by any data center goes to its cooling system. By isolating equipment based on specific temperature and humidity requirements, it becomes possible to optimize cooling systems by setting them to the most energy-efficient levels for each location [15].

III. PURPOSE OF THE PAPER

This paper aims to review and analyze the environmental impact of cloud computing and its data centers, given its increased demand and the energy consumption required. It will also explore eco-friendly approaches and strategies of green cloud computing that contribute to environmental sustainability.

IV. METHODOLOGY

- A survey targeting 65 individuals was conducted to measure community awareness about the impact of cloud computing on the environment
- Utilization of available datasets and assessments related to the carbon emissions of cloud computing data centers.
- Analysis of the available academic research and papers focusing on the same topic.
- Discuss and analyze best practices presented in related academic papers to identify sustainable and green cloud computing approaches.

V. ENVIRONMENTAL IMPACT OF CLOUD COMPUTING

Cloud computing became an expanded approach followed by most businesses and enterprises given the cost efficiency and scalability it offers to its users in addition to the role it plays when it comes to decreasing the need for hardware devices at the user's end; however, the increased adaptation of cloud computing comes with increased adverse environmental impact. Based on the articles and

related papers that were reviewed, below are the key issues that form the essence of the adverse effect of cloud computing on the environment:

• High energy consumption:
A data center is a central facility in cloud computing encompassing many connected hardware, including computers, switches, servers, etc., which forms the heart of the cloud as it stores business information and applications. A cooling system is also needed at each cloud center to maintain a suitable temperature for the hardware to work properly. All of the mentioned themes of a data center consume high energy and power that are mostly generated from fossil fuel, which harms the environment when it burns. A study [16] found that the electricity consumed by global data centers in 2010 was estimated to represent approximately 1.1% to 1.5% of the overall electricity consumption. The percentage for the United States fell between 1.7 to 2.2%. The global electricity consumption of data centers experienced a growth of approximately 56% between 2005 and 2010, rather than doubling. Devices such as laptops and smartphones connected to the clouds can consume up to 400 Tear wat, 2% of the global carbon footprint [17].

• Carbon emissions:
As mentioned above, the main energy source used to power the data centers of clouds comes from fossil fuels, which leads to huge amounts of carbon emissions that contribute to global warming and climate change. The multiple data centers that form the structure of cloud computing are responsible for 2.5% to 3.7% of global greenhouse gas emissions [18]. In 2020, around 300 metric tons of carbon dioxide were produced from energy used for cloud computing-related services and structures, according to the International Energy Association [19].

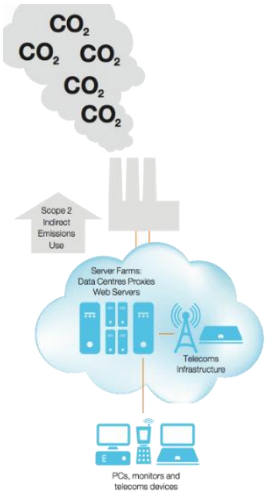

Figure 2. The structure of cloud computing and its CO2 emissions

Figure 3. Shows the amount of CO2 emissions produced by data center compared to other industries. Source [18].

• Electronic waste (E-waste):
Electronic waste refers to electronic items that are no longer wanted, working properly, or nearing the end of their life span. This term covers all kinds of electrical and electronic devices, including, but not limited to, home appliances, smartphones, and other electronic utilities. WEEE is another term researchers use to identify the same topic; the term stands for the waste of electronic and electrical equipment.
When it comes to cloud computing, the rapidly increased adaptation of cloud computing techniques led to an increased technological improvement in this field, which resulted in a high abandoned rate of old and outdated devices such as switches and services (data center equipment) with more advanced alternatives which will result in a high e-waste rate that contains hazardous materials such as mercury, cadmium and other materials that can harm the environment if not treated and managed properly. 53.6 MMT of electronic waste products were generated worldwide in 2019, of which only 17.4% were properly handled and recycled [20]. The remaining 82.6 % of the waste was disposed of in ways that were not environmentally [21].

• Water consumption:
Could computing rely on data centers, which are highly temperature-sensitive equipment that need continuous cooling due to their constant work and overheating? One of the main cooling techniques used is the water-based cooling approach, which consumes a lot of water daily. Data centers of medium to larger size utilize cooling tower-based chillers to enhance energy efficiency, resulting in on-site water consumption. Cooling towers use the process of water evaporation to remove heat from the data center, resulting in losses roughly equivalent to the amount of heat required to convert water into vapor.

Water usage from data centers has increased dramatically globally, from 738 million liters in 2015 to over 840 million liters in 2021; this is mostly caused by huge technological businesses using more water; a mid-sized data center in the United States -which holds around 25% of the global data centers- requires over 300,000 gallons of water a day, which is equivalent to the water use of 100,000 residences [22]. Google's data centers utilized around 4.3 billion gallons of water in 2021. A typical Google data center uses 450,000 gallons of water daily [23].

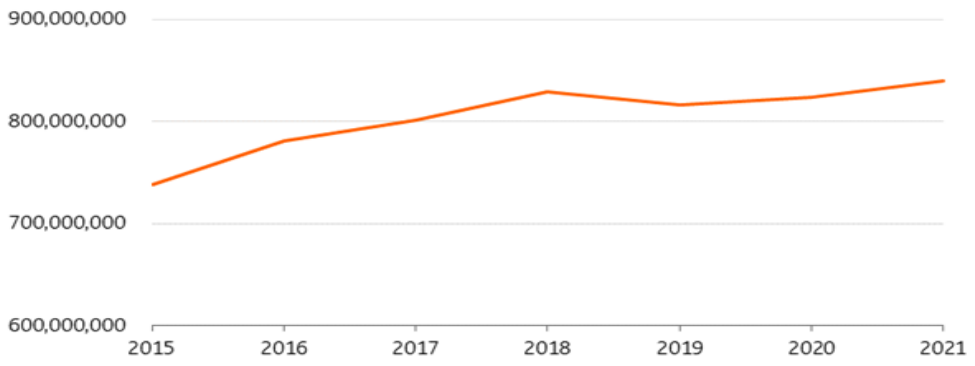

Figure 4. Water consumption of data centers globally in liters per day [22]

VI. GREEN CLOUD COMPUTING

The increased demand and adaptation of cloud computing services by users on a wide range escalate the adverse impact on the environment in many forms and ways, including (but not limited to) increased energy consumption, higher carbon emissions, e-waste, and water consumption. Therefore, cloud service providers need to adopt more environment-friendly approaches that can mitigate and minimize the harmful impact of cloud computing on the environment; such approaches and strategies are also known as green cloud computing.

Green cloud computing refers to the practice of creating, manufacturing, and utilizing digital environments in a way that minimizes their negative effects on the environment. An environmentally friendly cloud solution can conserve energy and greatly decrease businesses' operational expenses. Green cloud computing enables users to leverage the advantages of cloud storage while mitigating its negative impact on the environment, influencing humanity's well-being [24].

The objective of adopting green cloud computing strategies is to minimize the release of carbon emissions, which are responsible for global warming. Energy consumption is the primary cause of CO2 emissions. Therefore, by limiting energy consumption, we conserve energy supplies for the future and decrease CO2 emissions [25].

In her article, [24] mentions the basis of green cloud computing approaches and strategies as follows:

• Green design refers to the design of a cloud infrastructure that incorporates energy-efficient services, computers, software applications, and other equipment that consume less energy than their counterparts.
• Green production: The cloud architecture minimizes waste generated during recycling operations, creating a more sustainable environment.
• Green practices: results in a 27% decrease in energy consumption while utilizing a cloud-based solution.

VII. GREEN CLOUD COMPUTING APPROACHES AND STRATEGIES

There are several approaches followed by tech companies and cloud service providers that are introduced and adopted to mitigate the environmental impact of cloud computing; each one of those green approaches tackles one or more of the issues that form the base of the adverse environmental effects as follows:

• **The use of renewable energy sources and less power**: As stated above, fossil fuel was the main source of electric energy that feeds and operates the cloud's data centers, contributing to higher carbon emissions. To overcome this, cloud service providers must start integrating and transitioning to renewable energy sources such as solar, wind, and hydroelectric power as the main energy sources for their data centers, which will dramatically reduce carbon emissions. Many studies and research have been looking for alternative ways to reduce the energy data centers consume. Their article [26] proposed the (DEWTS) algorithm, which stands for energy-efficient workflow task scheduling, which aims to optimize energy usage and performance by utilizing DVFS technology to allocate parallel programs to units with slack time, integrating comparatively inefficient processors in the process, all within a specified deadline.

Another way to reduce energy consumption is by shutting down idle servers, which involves minimizing the number of servers being used for tasks and powering off servers experiencing low activity levels to decrease energy usage. In their paper, [27] presented a new approach called (ON/OFF), which requires only the loaded servers to work (ON) and the rest of the servers to be in sleep mode; the energy reduction following this method can be up to 40%-50%.

• **The geographical location of the data center**: it is important to plan and choose the most appropriate locations to operate the data center in; the data center location should have reliable access to renewable energy resources in addition to having favorable weather conditions that can guarantee both a renewable energy source (solar, wind) and reasonable temperature that will not drive the data center to overheat easily as data centers located in colder climate conditions can use the cold air from the outer environment to keep the IT devices within the desired temperature. Data centers situated in regions that procure their electricity from a green power provider will exhibit a significantly reduced carbon footprint compared to sites powered by gas or coal-fired electrical generators [18]
Another location-related conservation is the time the data travels; as we know, Data rarely follows a direct path from the sender to the destination. Instead, it follows a winding path through networks, routers, and switches, each of which has the potential to introduce latency, which means more power consumption [28].

• **Effective cooling approaches**: According to [14], almost %40 of the total energy consumed by any data center goes to its cooling system; therefore, adopting innovative and efficient cooling techniques such as liquid cooling and temperature management approaches will play a key role in reducing the energy consumed by the cooling system, leading to less energy consumption and fewer carbon emissions.
Corporations often utilize natural pre-cooling processes to reduce their reliance on cooling electricity. Facebook has established its data center in Sweden, exploiting its naturally wet and cold climate. The Belgian data center operated by Google does not have a complete chiller system and relies exclusively on "free" cooling methods at all times [9].
Immersion cooling is another technique used to cool IT systems in data centers by submerging the device directly in a liquid that does not carry electricity; immersion cooling offers the possibility of reusing energy, allowing data centers to decrease their carbon emissions by up to 45% in comparison to conventional cooling techniques [29].

• **Minimizing water consumption**: In relation to the above point, water in data centers is mainly consumed as part of the cooling system and processes; cloud data centers need to implement and adopt water-effect cooling approaches such as the immersion cooling teaching mentioned above. Cloud service providers can also benefit from available renewable water sources such as rainwater.
Data centers can harvest rainwater in many ways; however, the most efficient way is through blue roofs. Additionally, reusing and storing the collected rainwater can mitigate the risk of nearby local floods and dramatically reduce the costs of water taxes with an eco-friendly frame of work [30].
Google followed an innovative approach that utilizes artificial intelligence (AI) and machine learning techniques to train neural networks within its data centers. This is done to enhance the efficiency of water consumption rate, monitoring, and water management [23].

• **Virtualization**: Virtualization is a consolidation approach followed in data centers that aims to create virtual services where many versions of virtual services can operate on a single physical server. This will eventually reduce the number of servers on the ground, resulting in fewer machines and, therefore, less energy needed. Virtualization can be achieved by utilizing software known as a hypervisor.
Demanding tasks in data centers requires substantial computational capacity, inevitably resulting in elevated energy expenses and a larger ecological impact on carbon emissions. Nevertheless, by effectively managing and optimizing virtual machines (VMs), enterprises can acquire valuable knowledge about power use and implement measures to enhance sustainability [31].

• **Effective e-waste management**: E-waste is usually produced when cloud service providers and data centers dispose of or upgrade their ITC components, including services, switches, and other hardware. Insufficient management and recycling of this e-waste would result in an adverse environmental impact due to its toxic materials.
In their survey that targeted 361 responders involved in data centers, only %28 of the companies are following e-waste management and recycling strategies, which is a low number compared to the increased volume of data centers and cloud service providers [32].
Introducing and adopting accountable e-waste management strategies and approaches that focus on responsible disposal, recycling, and reuse of ITC devices is needed to minimize e-waste generation; also, IT production companies need to be accountable for expanding the life span of the devices to mitigate the production of e-waste.

• **Eco-friendly IT devices and hardware**: the hardware structure of the cloud data centers can also contribute to the overall environmental response; for example, choosing reliable and energy-efficient services and other related IT devices can optimize the data center's working capacity and reduce the energy consumption rate when compared to other non-efficient hardware. In her article, [33] recommends using SSD storage techniques rather than the traditional hard disk technology as SSD uses less energy and has more efficient storage.

• **Public awareness**: Although many cloud computing service providers are doing their best to increase a green approach to cloud computing in various ways, this cannot be achieved without proper community awareness that would support the major companies' initiatives. Communities and individuals are the main stakeholders in this process as they can promote green approaches compared to traditional ones, which can help induce more movement by cloud service providers towards an eco-friendly path. Building community awareness should start with education in schools and universities; governments also play a key role in legislating policies that govern the overall approach and working environment of the data centers in their region. The following survey was conducted to assess public and community awareness regarding the impact of cloud computing on the environment.

VIII. THE SURVEY

A survey of 13 questions was conducted to measure the public and community awareness about the impact of cloud computing on the environment and to what extent people think cloud computing can harm the environment. The survey questions were designed in a way that can easily show how the responders are aware of and concerned about the environmental impact of cloud computing; the questions also focused on exploring the individuals and communities willing to accept and adopt environmental-friendly approaches to cloud computing and the willingness of the community to support green cloud computing approaches.
The survey questions also helped raise awareness about the environmental impact of cloud computing, as they brought the attention of the respondents who were unaware of this concept to do more research about it, as some of the respondents did.
The survey was designed to be online using the Kobo toolbox platform, targeting 65 individuals of friends and extended family members with different demographics and educational backgrounds.

IX. THE SURVEY FINDINGS

The total number of respondents was 65 individuals from different countries, backgrounds, and education levels, aged between 18 and 50. The findings showed that only %26 of the respondents were very familiar with the concept and term of cloud computing. In contrast, %59 of the respondents had limited knowledge (somewhat), %12 had no idea, and %3 were experts (extremely familiar) in cloud computing.

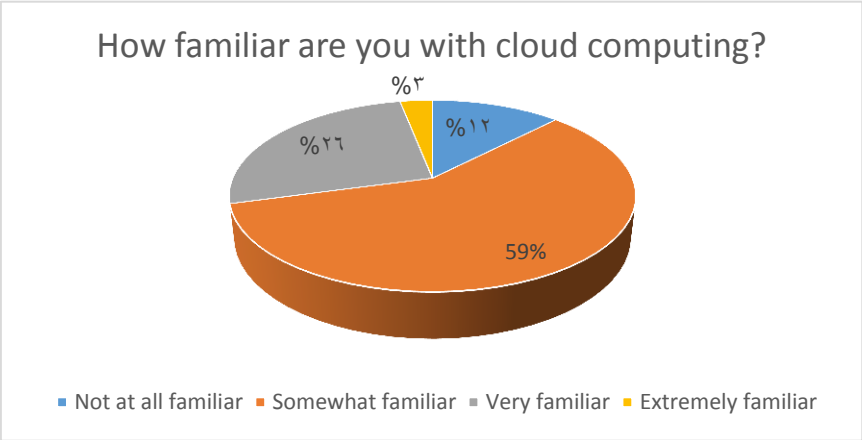

Figure 5. shows the cloud computing familiarity percentage of respondents

The findings showed that the majority of the respondents are engaged with one or more cloud-based services. However, the respondents' access rate differs as follows: 42% of the respondents access and use cloud-based services daily, 29% use them weekly, 17% use them monthly, 9% rarely use such services, and 3% report that they have never used cloud-based services.

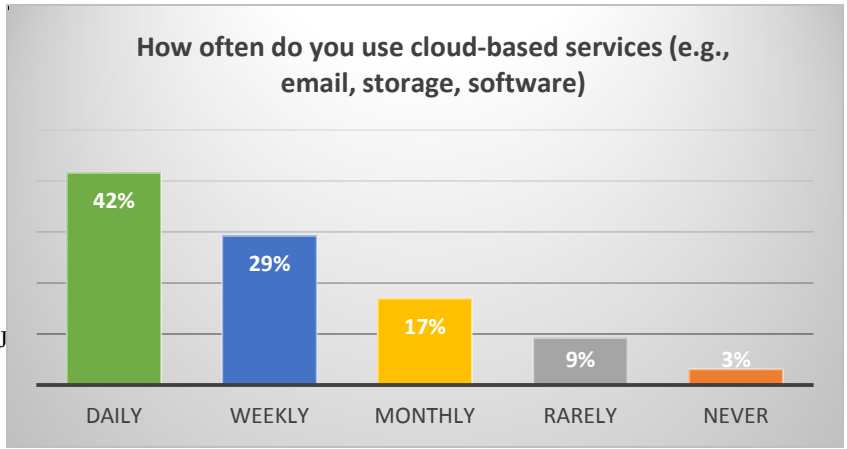

Figure 6. shows the usage rate of cloud computing-related applications

The respondents were asked about their awareness of cloud computing's environmental impact; the findings showed that 62% of the responses were unaware of that, whereas only 38% of the total respondents were aware of the environmental impact of cloud computing and its data centers.

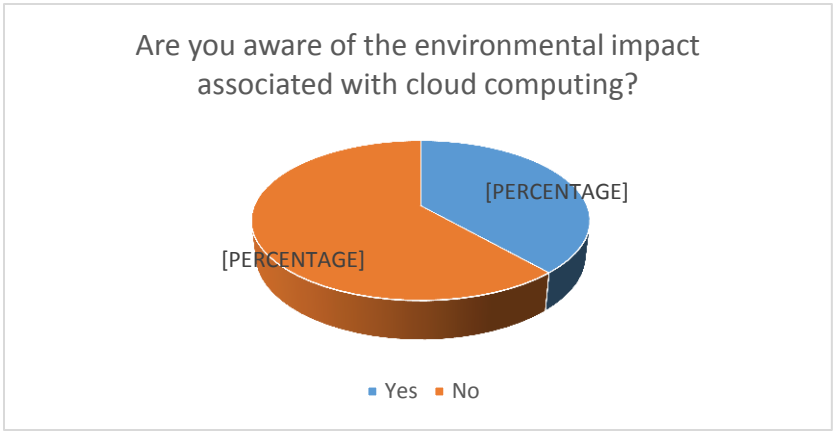

Figure 7. shows the cloud computing awareness level of respondents

The survey analysis also showed that only 34% of the total respondents are aware of cloud computing's contribution to higher energy consumption and carbon emissions, 40% are not sure about that, and 26% report that they don't think that cloud computing contributes to energy consumption and higher emissions.

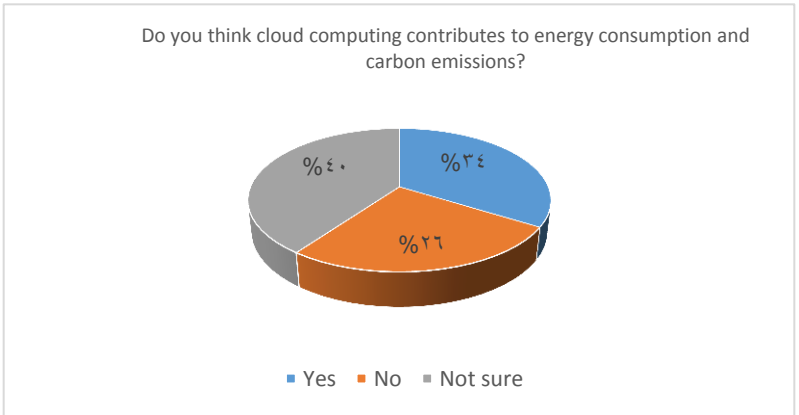

Figure 8. shows the respondents stand and awanress regarding cloud computing and its carbon emissions

As complementary questions, respondents were asked about their perceptions of cloud computing's contribution to energy consumption. 14% reported that it is very high, 15% reported that it is high, 35% reported that it is medium, 29% reported that it is lo, and only 6% reported that it is very low.

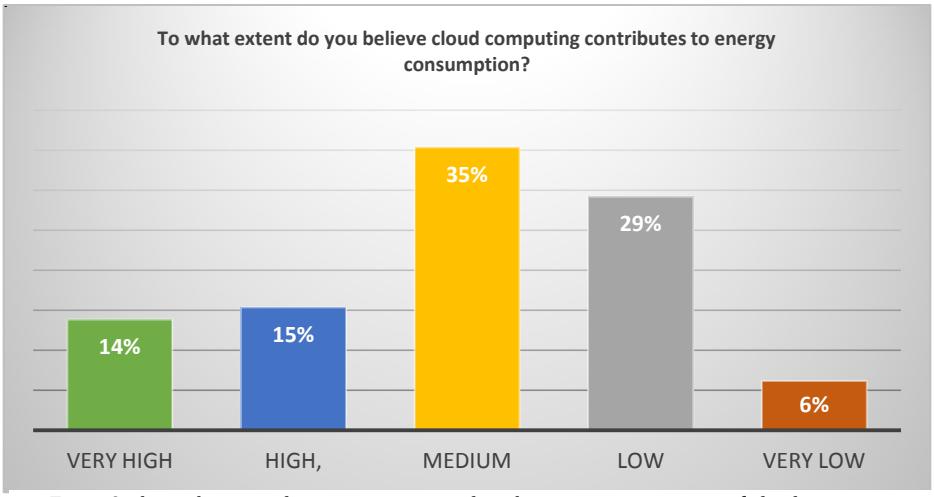

Figure 9. shows the respondents awareness regarding the energy consumptions of cloud computing

In terms of e-waste, the responders were asked about their awareness regarding the e-waste produced by cloud computing services; where only 34% of the responders think that cloud-based services and cloud computing are contributing to e-waste generation, 26% of the responders don't think so, and 40% were not sure about it.

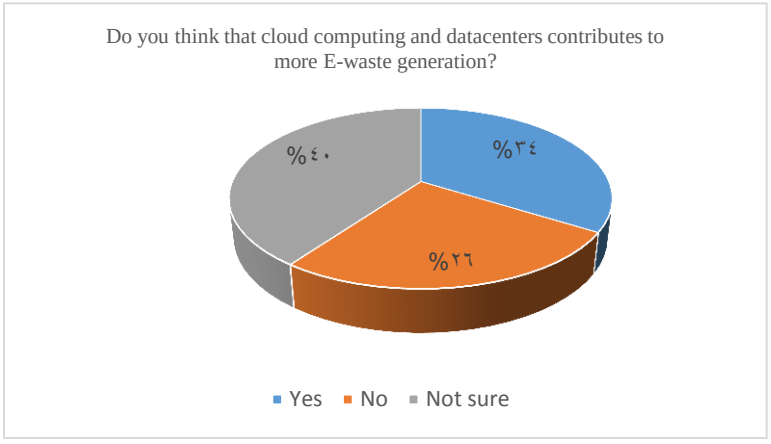

Figure 10. shows the respondents stand regarding the e-waste generated

35% of the total respondents agreed that the constant growth of cloud computing would lead to increased energy consumption, while 19% of the responders disagreed, and 46% were not sure about this concept.

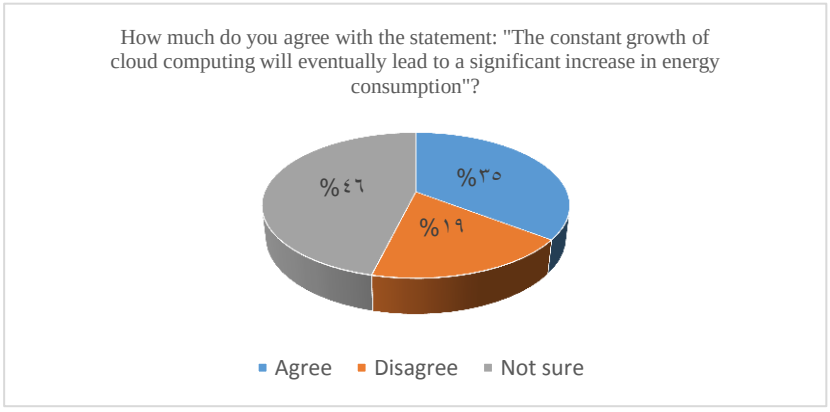

Figure 11.shows the respondents understanding of the future growth of cloud computing

Regarding green and eco-friendly approaches to cloud computing, 94% of the responders reported that it is important for cloud service providers and companies to prioritize green cloud computing approaches and strategies. At the same time, only 6% of the respondents reported the opposite.

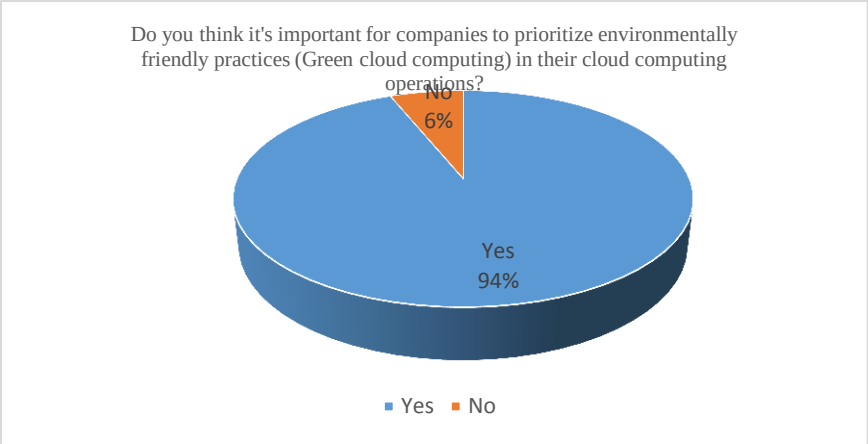

Figure 12. shows the respondents stand regarding green cloud computing

The survey analysis also showed that 85% of the responders were likely to choose a cloud service provider that adopts green and renewable energy sources. In comparison, 15% of the responders did not prefer it.

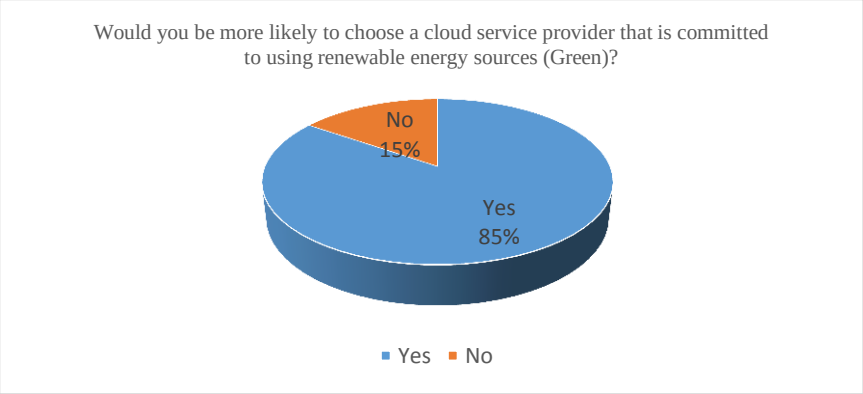

Figure 13. shows the respondents preference regarding green cloud computing

58% of the respondents stated that they are willing to pay slightly more for cloud computing service that follows an environmentally friendly approach (green cloud computing). In comparison, 42% of the respondents reported being unwilling to do so.

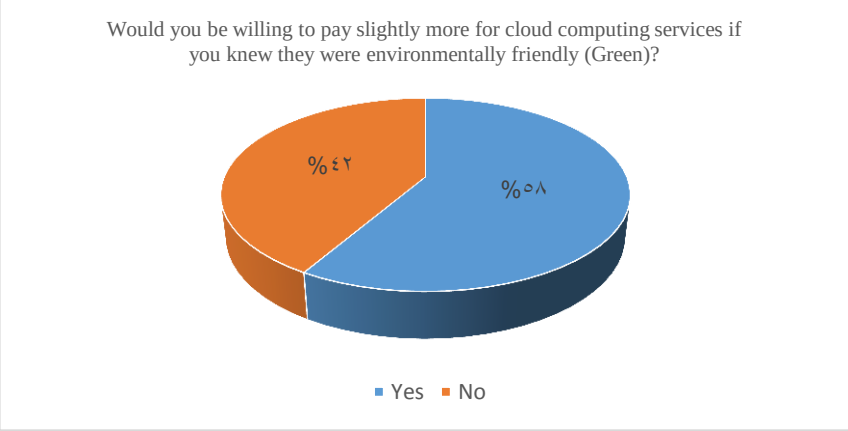

Figure 14. shows the respondents willingness to support green cloud computing

In response to the need for public awareness and education about the environmental impact of cloud computing, 91% of the respondents believed that raising awareness in this regard is important, while 9% of the respondents reported that it is not that important.

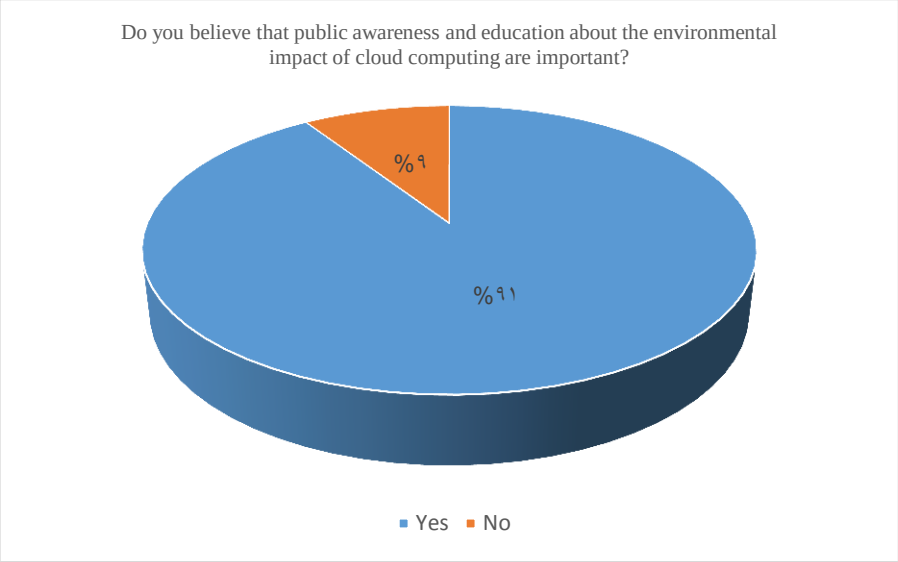

Figure 15. shows the respondents agreements to the need of more public awanress regarding green cloud computing

X. SURVEY ANALYSIS

The survey findings showed that 62% of the responders were unaware of the environmental impact of cloud computing, and 40% of the total responders were unsure if cloud computing contributes to higher energy consumption and carbon emissions. Those findings indicate that there is limited public awareness about the impact of cloud computing on the environment, which prevents key stakeholders (the community, the public, and individual users) from contributing to the endorsement of green cloud computing approaches and strategies. If such crucial stakeholders were well-informed and aware of the value that green cloud computing is adding to the safety and sustainability of the environing, they would act as better decision-makers when it comes to choosing the most sustainable, efficient, and eco-friendly cloud-based services as they have the willingness and likelihood to do so as 94% of the responders think that it is important for companies and cloud service providers to adopt green solutions. 85% of the respondents lean toward green cloud computing services, and 58% are willing to pay more for such green services.

Therefore, it is crucial to build community awareness (as 91% of the responders stated) about the growing issues of the adverse impact that traditional cloud computing is imposing on the environment, which can be achieved through campaigns and social media in addition to the education and schooling; additionally, government legislation should also be able to endorse and support the growing green approaches of cloud computing that service providers are starting to adopt while monitoring and addressing the ecological impact, carbon footprints and e-waste generated.

XI. CONCLUSION

The paper explored and identified the major issues and adverse impacts cloud computing imposes on the environment; the paper also highlighted the significant adverse effect of cloud computing, which is based on the increased levels of energy consumption, higher carbon emissions, e-waste, and increased water consumption used for cooling process which is directly proportional to the increased adaptation and access to cloud-based services by individual users and companies. The paper also discusses green cloud computing approaches as alternative strategies for mitigating and minimizing the environmental impact, focusing on renewable energy integration, energy-efficient hardware, virtualization, efficient cooling systems, e-waste management, and raising public awareness.

In a survey targeting 65 individuals of different educational backgrounds to measure public awareness about cloud computing, the survey analysis showed the need for building and raising community awareness about the environmental impact of cloud-based services, as 62% of the responders were not aware of it, on the other hand, there is a high agreement and willingness from responders regarding the need for prioritizing the green approaches in cloud computing as stated by 94% of the responders and the willingness of 58% of the responders to pay more for sustainable and green cloud computing services. Based on the survey findings, the paper recommended investing more in building public and community awareness about the importance of adopting a green cloud computing approach and its value through education, campaigns, and social media endorsed by governmental policies and legislation to ensure a more sustainable environment.

XII. APPENDIX

Public awareness survey about the imp

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