Dynamic Shift from Cloud Computing to Industry 4.0: Eco-friendly Choice or Climate Change Threat

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Abstract. Cloud computing utilizes thousands of Cloud Data Centres (CDC) and fulfils the demand of end-users dynamically using new technologies and paradigms such as Industry 4.0 and Internet of Things (IoT). With the emergence of Industry 4.0, the quality of cloud service has increased; however, CDC consumes a large amount of energy and produces a huge quantity of carbon footprint, which is one of the major drivers of climate change. This chapter discusses the impacts of cloud developments on climate and quantifies the carbon footprint of cloud computing in a warming world. Further, the dynamic transition from cloud computing to Industry 4.0 is discussed from an eco-friendly/climate change threat perspective. Finally, open research challenges and opportunities for prospective researchers are explored.

Keywords: Cloud Computing, Industry 4.0, Climate Change, Environment, Cloud Data Center, Carbon Footprint

1.1 Introduction

The world is waking up to the serious disaster caused by the ongoing global warming by the awareness efforts of young activists like Greta Thunberg. Climate change is a fact that threatens entire living ecosystems. Global web users are growing daily, and

Internet demand is building exponentially with every passing day [1]. Google is effectively and efficiently using emerging technologies and digital transformations such as Artificial Intelligence (AI), the Internet of Things (IoT) and the 6th Generation (6G) that require large cloud data centers to fulfil this user generated demand [2]. The expansion of cloud data centres furthers the rise in carbon emissions by enhancing energy consumption.

The large-scale consumption of energy and release of carbon have a negative effect on the Earth's climate, directly or indirectly, leading to melting of glaciers, rising sea levels and the ice-free Arctic. Rising temperatures are accompanied by changes in weather and climate [1]. Existing technologies are increasingly becoming fast and automated by the advancements in cutting-edge scientific research, however, these developments have come at the cost of an increase in the consumption of energy and resulting negative impacts on the ecosystems.

On 26 July 2019, in the heatwave event that broke records across Western Europe [2], Paris saw a record high temperature of 42.6 degrees Celsius (108.6 degrees Fahrenheit). While extreme weather events such as heatwaves happen naturally, according to the UK Met Office "research shows that climate change is more likely and perhaps as frequent as every other year". As early as 14 August 1912, the possibility of future warming by coal-burning through the introduction of carbon dioxide in the air was published by a New Zealand daily [3]. Previously estimates of the amount of carbon in the atmosphere are on the rise as cloud data centres are expanded to meet consumer demand. In order to minimize the carbon emissions by the increasing use of cloud data centres, the state-of-the-art cloud data centre management techniques were investigated by [1]. Moreover, an innovative solution to the global challenge of climate change has been developed to enable holistic resource management for reliable, energy-efficient and cost-effective cloud computing [4]. This study proposes the use of renewable sources of energy which could help to reduce the environmental impact of cloud data centres.

In brief, this chapter has two main objectives. The first is the development of various pathways based upon the demand of cloud computing in the future to quantify its role in a warming climate, and the second is the use of artificial intelligence-based techniques to take intelligent decisions for the cloud to minimize its negative impact on the climate.

The rest of the chapter is organized as follows. In Section 2, we discuss cloud computing. After that, we discussed Industry 4.0 in Section 3 and climate change in Section 4. Section 5 quantifies the carbon footprints of cloud computing in a warming world. Section 6 presents the dynamic shift from cloud computing to Industry 4.0. Section 7 explores future trends of cloud computing research, which can be an eco-friendly choice or climate change threat. Section 8 presents impact of carbon footprints on climate change and section 9 discusses open research challenges and opportunities. Finally, we summarize the findings and conclude the chapter in Section 10.

1.2 Cloud Computing

Cloud computing is a dynamic provisioning model that supplies clients on an on-demand basis from a shared pool of computing resources [40]. Using virtualization technology, several Virtual Machines (VMs) are created on each physical server to allow for efficient resource allocation and reductions in the amount of hardware in use [26]. The prominent cloud providers such as Facebook, Amazon and Google use a huge amount of Cloud Data Centres (CDC) and offer a very reliable and cost-effective cloud service to the end-users [1].

Recent years have seen the dramatic migration of applications and services to the cloud [27]. This paradigm allows organizations to outsource computer requirements and resources, promising features such as high scalability, agility and reliability [29]. However, as the popularity of cloud computing increases, energy consumption by its data centres is becoming more prominent. Cloud infrastructures consume a great deal of energy, accounting for 3% of global electrical energy consumption as of 2017 [1]. This high energy usage of has been attributed to energy inefficiencies and wastage. One analysis of energy wastage found data centres to use only 6-12% of electricity powering their servers to perform computations, with much of the remaining energy used to keep servers idle, ready to deal with potential activity surges [28]. There is a spectrum of disadvantages to this; from increasing environmentally detrimental carbon emissions, to driving up operating costs for cloud providers and the subsequent reduction in profit margin. Curbing the energy budgets of data centres is therefore both sustainably and economically incentivized but is not without challenges.

Despite brown energy becoming less favorable, it is evident that the solution will not be as simple as making the swap to green renewables. The production of energy from wind turbines and solar panels is weather limited. It remains a challenge to balance intermittent green energy production with continuous functioning requirements of the data centre, without compromising on Service Level Agreements (SLA) or Quality of Service (QoS) [26]. Other potential solutions explore green architectures involving client-orientated green cloud middleware to assist in energy-efficient decision making. For example, Hulkury and Doomun propose a user interface application which gathers system specifications such as SLAs and QoS, and returns the estimated carbon footprint for each business operation as performed on the client's machine, a private cloud or the public cloud with the aim of recommending the 'greenest' option for the job [40]. Kuppusamy also proposes an adapted middleware for managing the selection of Cloud provider with the lowest carbon emissions, based on parameters such as data centre cooling efficiency [41]. Future challenges and opportunities are explored further later in the chapter.

1.3 Industry 4.0

As the efficiency of hardware and software systems have increased in the last few decades, modern computational frameworks are able to perform tasks with much lower result delivery times, cost and energy consumption [11]. On the other hand, the service requirements of different industrial sectors like manufacturing, supply networks, agriculture and healthcare have become more demanding over the years [6] [12]. Moreover, modern cloud-based infrastructures have contributed to a significant portion of global energy consumption and have played a critical impact on the carbon footprint [1] [10]. For the growing user demands, by leveraging novel technologies, the industry and academia have started the fourth industrial revolution.

The fourth industrial revolution, named as Industry 4.0 marks the complete shift in the technological backbone of industrial applications. This revolution is marked by the upcoming paradigms such as the IoT, AI and Blockchain [6]. The new paradigm on IoT allows end-to-end integration of sensors and actuators close to the user with geographically distributed cloud servers via a large number of intermediary smart edge/fog nodes [13]. This allows the development of a hierarchical and more robust infrastructure for modern industrial applications [9]. The new field of AI allows users to utilize and exploit large amounts of sensor information using big data analytics to properly and efficiently manage resources, prevent service failures and provide high-quality results [14]. Furthermore, technologies like Blockchain allow strong data integrity to prevent fraudulent data manipulation and provide strong support to various Machine learning algorithms which depend on this data [15]. New paradigms require the development of novel security measures to prevent attacks like evasion, data poisoning and model stealing [16]. All these challenges need to be solved in diverse areas with a primary focus on sustainability.

1.3.1 Healthcare 4.0

Healthcare is one of the most challenging domains with respect to providing efficient services using innovative computation models and advanced algorithms [37]. This difficulty primarily arises from the critical need for ultra-precise results in extremely small amounts of time with low latency, response time, and high accuracy [37] [38].

Many recent works aim at providing effective healthcare services leveraging next-generation technologies at affordable costs [5] [38] [39]. This requires optimizing the existing models used for leveraging diverse computational frameworks in a seamless fashion. This is done to enhance the abilities and provide higher quality disease detection results, improved automated prescription generation and reduce service costs.

To effectively leverage computational technologies, prior works use advanced scheduling and offloading approaches like genetic-algorithms, machine learning and reinforcement learning [37, 38]. Many prior works utilize data sharing capabilities of Network Attached Storage (NAS) to further reduce the allocation times [44]. Recent works also leverage microservices and container-based deployments to further enhance the efficacy of intelligent scheduling policies. Furthermore, with the advent of computationally powerful edge devices researchers have been able to run sophisticated federated learning policies for holistic improvement of QoS parameters like energy and response time which are crucial for time-critical healthcare applications [44]. Other works aim to minimize SLA violations. Violating SLA could lead to catastrophic impacts on critical applications like e-healthcare. Hence, novel approaches are required which are able to not only manage large-scale healthcare solutions but also have extremely low overheads.

The driving idea of the future-proof model is to utilize and build upon techniques of AI and machine learning for efficient task scheduling and placement to achieve the above-mentioned objectives [6]. However, there still exist several pragmatic challenges remaining to be solved. Most of the AI-based approaches are suitable for cloud setups which have GPUs for faster training of the underlying neural networks and results generation [8]. This not only increases the cost and power consumption of such deployments but also limits such frameworks to be only deployed in resource-intensive data centres [7]. This is not suitable for low resource-based Edge deployments which are the upcoming paradigm, being readily leveraged by modern industries. Thus, AI not only allows the development of precise and accurate computational services crucial for the healthcare sector, but it also poses challenges like scalability, affordability, security, high-availability, energy and budget limitations.

1.3.2 Agriculture 4.0

The traditional approach of the agriculture industry is undergoing a fundamental transformation. Advance research-driven worldwide global trends are affecting the agriculture industry. Various researchers, academicians and industries are developing new agriculture systems [30] [31], enabling the automation of agriculture industry and improving agriculture as a service using new digital transformations such as AI, 5G, IoT and edge computing. Cloud computing uses a large number of CDCs to provide the required computational capacity. Due to the use of a huge number of data centres, a huge quantity of carbon-di-oxide is generated, which further impacts the climate. A large amount of energy is required to run the CDCs continuously to maintain the QoS. To solve this problem, renewable sources (wind energy, solar energy etc.) should be utilized to run the CDCs, which can reduce the impact of cloud computing on climate saving a large amount of brown energy.

1.4 Climate Change: Projected Warming in the 21st Century

The increase in greenhouse gas emissions across the globe is expected to inevitably lead to 1.5-degree warming and there is a very small window available to avoid reaching the stipulated warming which is also estimated to be a tipping point for various climatic systems across the globe [32]. The projected increase in greenhouse gases can eventually lead to an increase in global surface temperatures on Earth, changing the regional patterns and amount of rainfall, reduction in snow and ice cover and leading to damages in permafrost, raising the mean sea levels, increasing extreme storms and rainfall events, increased acidification of the oceans, change ecosystems and eventually threatening human life. These impacts are not just limited to future projections but have rather started showing up in various forms in nature. These changes in future heavily depend upon the role of anthropogenic activities and are quantified by different pathways by Intergovernmental Panel on Climate Change (IPCC) based upon projected emissions under different scenarios. A recent study [33] has shown that the changes in sea-level rise could be thrice as compared to previous estimates endangering major coastal cities with flooding worldwide. There is no doubt that climate change is already a global problem created by humanity and it is leading to catastrophic impacts all over the world. The first solution is a reduction in emissions but quantifying the role of different sectors remains a challenging task. At this stage when global warming has become an international calamity, increasing sources such as, for example by cloud computing, is the last thing humanity can afford.

1.5 Quantifying Carbon Footprints of Cloud Computing in a Warming World

According to the IPCC Assessment Report 5 [34] [35], the rise in global average surface temperatures have been primarily driven by anthropogenic activities. Until

2010, the rise has been 0.6° relative to 1950 [34]. The warming has been on the rise and it has been recently projected that a 1.5° rise which may be unavoidable would trigger tipping points [36]. In the past 3 decades, there has been a lot of research focusing on various sources of greenhouse gases-led global warming, such as the burning of fossil fuels, the release of methane etc. However, studies focusing on the role of emerging technologies in driving the warming have been limited. Further, we can quantify the role of cloud computing infrastructure and its maintenance activities as drivers of global warming acting as carbon sources. There has been an increase in the establishment of new cloud-based servers globally, and these servers require a continuous supply of electricity. Thus, quantifying the role of cloud data centres for their impact on the global climate is an important question that needs to be asked for decision-makers. This activity would employ data from various cloud servers and an AI-based inverse modelling approach to quantify their role in warming the climate. This would require expertise in climate, data science and cloud computing.

1.6 Dynamic Shift from Cloud Computing to Industry 4.0

Cloud computing has been readily adopted by most industrial and academic sectors in the last few decades. Computation on the cloud allowed users to leverage geographically distributed services and give application developers or service provider’s hassle-free computational framework. The original cloud enterprise model consisted of four main layers: personal device layer, an interface layer, management layer and physical layer. The device layer, which included personal laptops, desktops and mobile phones, allowed users to interact with a frontend interface of the cloud service. Many advancements have taken place allowing diverse devices to be able to interact with the cloud platform [17]. The interface was supported by various technologies of key-exchange, encryption and signature-based certification to maintain security [18]. Many works have also focused on providing different types and more-user friendly interfaces to allow easy integration and quick deployment of cloud services in the industrial pipeline [17]. Above the interface layer is the management layer which manages the tasks across different computational nodes by either a form of load balancer or scheduler [19]. The management layer was also developed to be robust and provide high-availability using recovery management for fail-prone cloud servers [20]. Many works have also allowed the integration of large-scale database management systems with the cloud through the management layer [21] [38]. Finally, there is the physical layer which provides the underlying computational infrastructure which computing nodes being either physical servers of virtual machines deployed on such servers. However, the Industry 4.0 revolution revamps this design for the next-generation industrial demands.

Industry 4.0 employs state-of-the-art technologies for providing optimum quality with a scalable computational platform which is strongly integrated with the new IoT paradigm. The user-level devices are now sensors or actuators with limited resource capabilities in embedded devices. This not only provides low latency response but also brings computation closer to the edge of the network allowing high scalability using hierarchical architecture [21]. The interface now consists of multiple micro-services instead of monolithic cloud service, catering to different user needs efficiently [22]. Data and interaction security are maintained with smart contacts, smart management and sophisticated data recovery mechanisms [23]. Further, the management layer now consists of AI and ML-powered scheduling algorithms [24] with high integrity Blockchain mechanisms [21] for fast, accurate and tamper-proof application deployment. Hybrid infrastructure in the physical layer consisting of both edge and cloud nodes allow efficient allocation of low latency tasks to edge devices and high accuracy tasks to cloud servers [24]. Virtualization has now shifted to lightweight containers for supporting resource-constrained fog nodes and quick task migration to prevent application failures [25]. A summary of the paradigm shift from cloud enterprise through Industry 4.0 is shown in Figure 1.

1.7 Eco-friendly Choice or Climate Change Threat

Whether cloud computing is an eco-friendly choice or a climate change threat is yet to be determined. This would require quantification of the contribution of cloud computing towards carbon emissions. In future, the new methodologies for climate change mitigation to negate the impacts of cloud computing on climate will focus on the development of algorithms which would efficiently decide which servers to shut down and which ones to keep up depending on their carbon footprint and requirement. Machine learning based data analysis will be highly useful in achieving these goals. The use of online agents which would continuously monitor the cloud resources and take decisions looks promising and will be helpful in eliminating the human error in these activities.

1.8 Impact of Carbon Footprints on Climate Change

Anthropogenic activities are adversely impacting the environment. Since the industrial revolution (1850s), global warming and associated changes in the climate due to enhanced greenhouse gases (CO_2, CH_4 and others) has become a major challenge for the survival of life on Earth [48]. Starting 21st century, the end users are using a large number of edge devices such as mobile phones, laptops etc. to get quick services in a reliable manner [4]. For example, people want to access Facebook and other websites on the Internet without any delay and there is a need to deploy millions of servers to fulfill the increasing demand of the users. The cloud data centers are growing continuously further consuming high amounts of electricity.

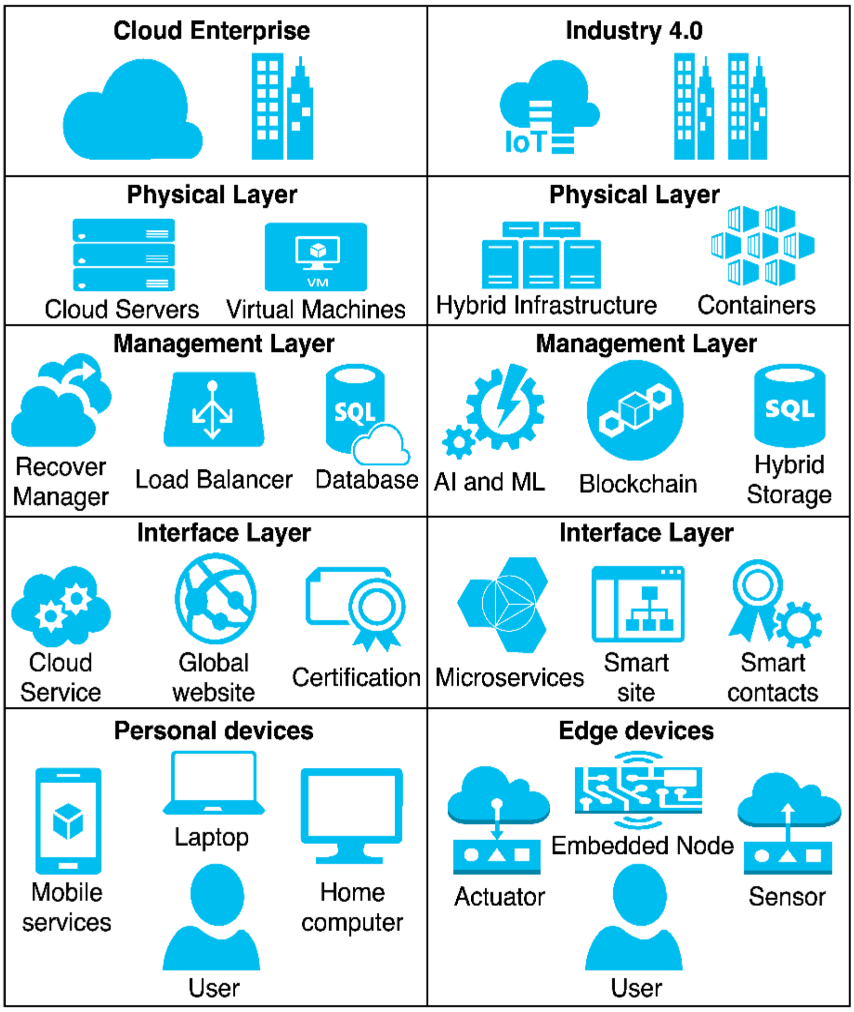

Figure 1: Summary of a dynamic shift from the cloud through Industry 4.0

A major chunk of electricity produced worldwide comes from burning fossil fuels having large carbon footprints [1]. Further, the growing utilization of unclean energy sources are creating major environmental challenges such as worsening of air quality (fog, production of photochemical smog and tropospheric ozone, heavy metal pollution, etc.), fluctuation of water quality (due to discharge of pollutants to water bodies), immense pesticide usage, acid precipitation (from coal combustion that leads to SO2 and thus sulfuric acid) and ozone layer depletion (due to the use of chlorofluorocarbons) [49] [50]. To solve, this problem, there is a need to develop more energy-efficient resource management techniques which can optimize the use of energy and have low to nil carbon footprints [27].

1.9 Future Research Challenges and Opportunities

In this section, we discuss future challenges and opportunities for prospective researchers. Figure 2 shows the promising future directions and opportunities.

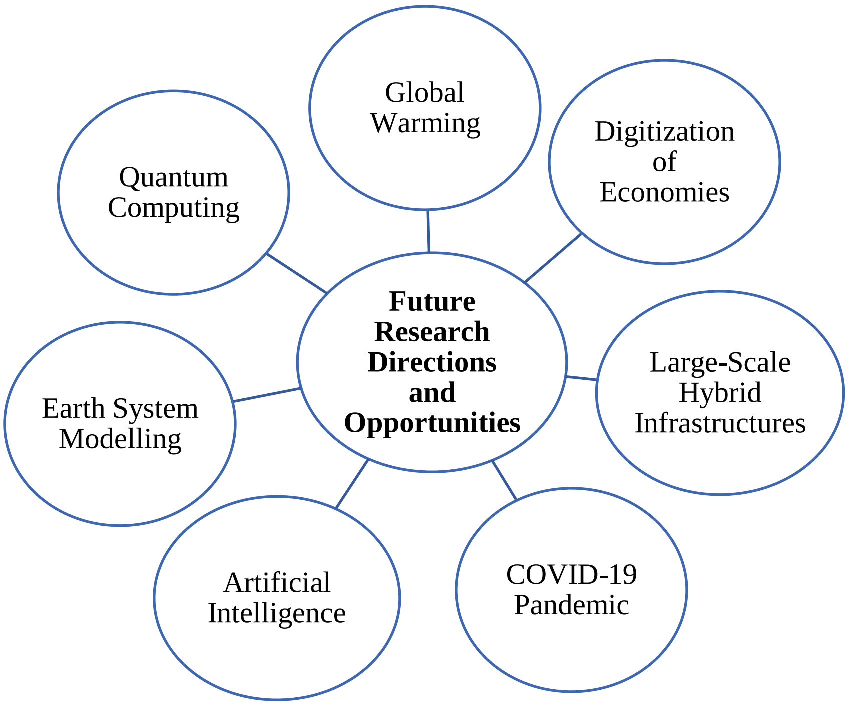

Figure 2: Future Research Directions and Opportunities

1.9.1 Role of Cloud Computing in Global Warming and its Quantification

The role of cloud computing as a source in emitting greenhouse gases via the consumption of dirty electricity has to be quantified for devising future projections on climate change. In this aspect, this study aims to calculate numbers for various pathways that would be developed considering the demand for cloud computing in the future. The outcomes will lead to a better understanding of the percentage of electricity consumed by the emerging technologies associated with the cloud originating from fossil fuel burning. The development of such pathways will be useful for policymakers and also for incorporating cloud computing as a source in the IPCC assessments in future. The requirement of Facebook and Google of today to continuously keep their servers up with an increasing population adopting the Internet is expected to make cloud computing as having a major carbon footprint in the future.

1.9.2 Increasing Digitization of Economies

The increasing digitization of economies across the globe is leading to the development of cloud data centres which are important for driving the digital world. However, the development and maintenance of these cloud data centres have a carbon footprint which is increasing day by day and contributing to the anthropogenic sources responsible for global warming. In future, there is a need to quantify the role of these data centres in their capacity to cause global warming, helping stakeholders in Europe, USA and across the globe to develop policies for the future.

1.9.3 Development of Novel Frameworks for Large-Scale Hybrid Infrastructures

As the demands in service industry increase, there is a need for novel frameworks that can exploit the low latency of edge nodes and also high computation power of cloud servers. Such frameworks must maintain a careful balance between accuracy requirements and response times for different healthcare tasks. For such a framework, real-time analysis of critical patients can be done at the most powerful edge resources or the closest cloud servers. Other healthcare services with long deadlines can be run on distant cloud data centres, and those with low compute and low response time requirements can be run on cheaper and resource-constrained edge nodes. This itself requires robust scheduling and task placement algorithms to be built for seamless integration of different paradigms and meeting the SLAs.

1.9.4 Pandemic Induced Reduction in Emissions due to Cloud Computing

It is known that the climate has been changing towards a hotter planet hitherto since the industrial revolution. Increasing temperatures have also been associated with degrading air quality across major industrial centres around the globe [51]. The air quality has been declining due to rampant and unsustainable development activities undertaken by humans. However, recent COVID-19 [52] enforced global lockdowns have led to a drastic improvement in the quality of air around the world. These improvements in air quality were last observed during the global economic recession of 2008-2009 [42]. However, it was seen that some countries took on a path of steep development leading to the coinage of the term "revenge pollution" [43]. Suppression of pollutants in the air has hence been associated with economic slowdowns or pandemic related lockdowns which are expected to be followed by periods of enhanced aerosols in the atmosphere. The quantification of the role cloud computing plays in this suppression and enhancement of pollutants would be important for devising policies in the future.

1.9.5 Role of artificial intelligence in tackling climate change

One of the biggest problems facing mankind is climate change machine learning can help in solving the multi-faceted challenge of global warming and climate change [53]. Machine Learning can deliver important contributions in addressing climate change challenges across domains (for example, see [45]). It can allow automated monitoring by remote sensing satellites helping the task of scientific exploration and maximizing productivity systems. Artificial intelligence can speed costly physical simulations by hybrid modeling. It must be remembered that AI is only part of the solution allowing other methods used in climate change science across fields. Applying machine learning to combat climate change related problems has the potential to support humanity and advance machine learning. Meaningful progress on climate challenges involves dialog with disciplines within and beyond computer science, and may lead to interdisciplinary methodological developments, such as enhanced data-driven approaches that are limited to physics. Unlike traditional AI-benchmarks, wherever climate data exists, it may not be structured for a single purpose. Datasets can contain heterogeneous source information and must be combined with domain expertise. The existing data does not reflect global usage cases. As an example, the data for US weather forecasting or energy demand is plentiful, however for Africa it is scarce. Transfer learning techniques and domain adaptation would undoubtedly prove necessary in low-data environments. For certain tasks training with carefully generated simulation data might be feasible. However, the better alternative is still the more actual observational datasets.

1.9.6 Earth system modelling and advances statistical techniques using cloud computing for climate change research

Earth System models are global environmental models with the integrated potential to directly reflect biogeochemical mechanisms that communicate with the real climate, thereby altering its reaction to forcing like the one associated with anthropogenically-driven greenhouse gas emissions. Representing the climate system requires feedback between the physical atmosphere and the water and land chemical-biological cycles that eat up the carbon dioxide produced, thereby minimizing warming. Such models offer important insights into climate instability and transition, and the impact of human activity and potential mitigating measures on future climate change. The use of ESMs and the advanced statistical techniques such as the one by [46] can help in estimating the climate response to natural and anthropogenic forcing. Various advanced statistical methods such as causality, complex networks, recurrence plots, deep learning, deep reinforcement learning and others offer hope in providing interesting insights into the mechanisms behind climate change and science. The explosion of climate data in the last two to three decades and the advent of cloud computing offers with the correct analysis, storage and reproducibility becoming big problems in climate science, cloud computing solutions such as Google Earth Engine offer new paradigms for the climate science community.

1.9.7 Role of Quantum Computing in Climate Control

Quantum computing is expected to become very effective in handling different problems related to climate change such as energy production, carbon capture and storage of carbon, which are the main reasons of production of CO2 emissions [47]. Further advancements in the quantum computing can aid to simulate large complex molecules, which further helps to discover new catalysts for carbon capture economically. Moreover, Quantum computing can aid in extremely high-resolution simulations of weather and climate models of the future. Cloud-computing will play a crucial role in driving the advances driven by quantum computing in future.

1.10 Summary and Conclusions

In this chapter, we discussed the impact of cloud computing transformations on climate and presented the role of cloud computing in global warming. This chapter quantifies the role of cloud computing on climate change in the future depending upon various representative concentration pathways that would be developed. There is a need to develop a system which would be targeted at reducing the carbon footprint of cloud computing infrastructure. This chapter can potentially help future researchers in two ways: First, it would help the policymakers involved in the business of cloud computing to develop climate-aware policies for the future. Second, the development of a system to assist in cloud computing activities will also aid in reducing the carbon footprint of the cloud in the future. Moreover, we proposed some promising research directions based on the analysis that can be pursued in the future.

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Glossary of Terms

Terms	Description
Cloud Computing	It is on-demand cloud service (using resources such as processor, storage, memory and network) to the users via Internet.
Industry 4.0	Current trend of automation and data transfer in manufacturing technologies.
Climate Change	Change in the mean or basic state of the climate.
Eco-friendly	Anything that does not harm the environment.
Quality of Service (QoS)	It is a measurement in terms of performance parameters to evaluate the service quality.
Service Level Agreements (SLA)	SLA is an official document, which is signed between cloud user and cloud provider based on QoS requirements.
Agriculture 4.0	Atomization of Agriculture related aspects such

	as precision agriculture and big data analytics.
Healthcare 4.0	Management of vast amount of healthcare data efficiently.
Carbon Footprints	It is the amount of carbon released in the environment by the computing system.
Digitization of Economies	The transition of financial systems towards digital platforms.
COVID-19 Pandemic	It is a coronavirus disease 2019, which is caused by SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2).

List of Acronyms

CDC: Cloud Data Centres

AI: Artificial Intelligence

IoT: Internet of Things

6G: 6th Generation

VMs: Virtual Machines

SLA: Service Level Agreements

QoS: Quality of Service

NAS: Network Attached Storage

IPCC: Intergovernmental Panel on Climate Change

List of Index of terms

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