Revolutionizing Businesses in the Cloud and Their Profound Impacts on the Digital and Physical Future

A Research Paper Submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science

University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements of the Degree

Bachelor of Science, School of Engineering

Ethan Tran

Spring 2024

On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

Advisor

Bryn E. Seabrook, Department of Engineering and Society

Cloud Computing Introduction

The future of technology resides in the cloud, not a mythical land of virtual storage but a revolutionary shift towards serverless technology for businesses and organizations. This future is defined not by physical servers but by a cloud environment that is both flexible and dynamic, capable of harnessing the benefits of technological revolutions through virtual servers. Cloud migration takes businesses to the forefront of cutting-edge technology, enabling them to revamp their entire infrastructure and leverage the benefits of cloud computing to remain competitive in the global market. Cloud migration involves transferring data, applications, and software from on-premises servers to cloud-hosted virtual servers provided by companies such as Amazon Web Services (AWS) and Microsoft Azure.

This transition is driven by the growing global dependence on data centers, which have become essential to modern society akin to power plants. However, this increasing reliance on data centers raises ethical concerns regarding their environmental impact, particularly concerning energy consumption and lack of renewable energy sources. Cloud users will only grow exponentially over time, with cloud now being the industry standard, pressing for an even greater reliance on data centers. As cloud computing continues to become the primary computing system, it is imperative to carefully examine its environmental implications within the framework of environmental ethics. This research addresses the overarching question: How can we balance the performance benefits of cloud migration with the imperative of environmental sustainability? This paper aims to contribute to the ongoing discussion on sustainable technology development and responsible innovation in the digital age through interdisciplinary analysis and ethical inquiry.

Navigating a Greener Cloud: Research and Methods

This cloud research aims to answer the question of how cloud migration's benefits can be balanced with the imperative of environmental sustainability and ethics. The research employs a qualitative analysis method to address this predominant issue of finding balance within the current cloud, focusing on a systematic literature review and case studies. The study primarily draws upon academic journals, articles, and global environmental impact reports of data centers. These sources provide the foundational knowledge and environmental ethics framework necessary for analyzing the environmental impacts of cloud migration. The research is guided by keywords such as "cloud computing," "sustainability," "data centers," and "environmental ethics" to discover practices and techniques to limit the environmental impact of cloud computing. The research methods encompass evaluating energy-efficient practices and algorithms, adopting renewable energy sources, and examining the impact of regulatory frameworks on promoting sustainable energy use within data centers. By integrating environmental ethics into the analysis and comparing case studies on successful sustainable data center innovations, this approach aims to find what it takes to adjust the current cloud migration trajectory to a greener, more sustainable future. The rest of the research paper is organized into three critical literature review sections for the results, with case examples emphasizing the significant steps needed to ensure environmental ethics. The literature review is followed by a discussion to discover what the future must entail for a sustainable cloud.

The Environmental Conundrum of Cloud Migration

In order to provide a comprehensive understanding of the environmental ethics surrounding cloud migration, it is essential to delve deeper into the contextual factors shaping

this technological shift. Cloud computing has been around since 2006 but has only recently taken flight as a cardinal service where businesses and users can utilize it as an infrastructure as a service, software as a service, and platform as a service. The major draw to the cloud is its versatility and flexibility while maintaining the business or user's identity and core intent. The benefits of the cloud are seemingly endless, such as accessibility, efficiency, scalability, and, more importantly, the potential of the applications and software to spark innovation with all the new tools and metrics from cloud computing.

The desire to capitalize on cloud services and reap the benefits drives cloud migration. However, as organizations migrate their operations to the cloud, there is a growing recognition of the environmental impacts associated with this transition. Central to this discussion is the dramatic increase in reliance on data centers, the backbone of cloud infrastructure. Such demand has sparked the continuous construction of data centers around the world. However, the location and infrastructure supporting the new centers are sourced mainly from fossil fuel energy areas and areas lacking sustainable options. Data centers consume vast energy and resources, leading to concerns about their carbon footprint and sustainability. Moreover, the redundancy and standby requirements of data centers, necessary to ensure constant, uninterrupted standby service for users, further exacerbate energy consumption. Data centers require vast amounts of energy to keep the data available and servers cooled, while little energy is spent on actual computations and functionality of applications. Due to data centers not being heavily regulated, they have caused issues in communities due to their proximity to civilians, causing noise pollution and droughts (Monserrate, 2022). As cloud computing continues to gain traction as the primary computing paradigm, it is essential to examine its environmental implications critically. There is a dire need for regulations in data centers to improve the control over energy consumption

sustainability. By addressing the overarching question of balancing performance with environmental sustainability, this paper aims to discover what it takes for a successful, continuous green cloud future.

The Importance of Environmental Ethics

The main issue of modern-day cloud computing is the environmental ramifications of the current environment; the current trajectory of this technological migration cannot be sustained at its course. The framework to analyze the impacts of cloud migration is environmental ethics, providing a substantial context for understanding the complexities inherent in this technological revolution. Cloud migration is an example of a technological phenomenon that can change the world, but only if done and sustained correctly for the future. New technological trends come every year and seemingly every month in this digital age. However, if the ethics concerning the environment are made apparent after full-scale adoption, more work will need to be done to correct the damage cloud and current-day technology have done.

In considering the environmental ethics of cloud migration within the framework, it is imperative to acknowledge the uncertainty factor inherent in environmental risks. According to Gilroy, environmental risks are unique to potentially catastrophic costs, such as the inability to calculate worst-case scenarios from non-traditional sources (Gilroy, 2018). Cloud computing is the first of its kind; large-scale data centers across the globe running always have never been dealt with before. His example in his paper highlights how traditional pollution can be accounted for, but the new mix of synthetic nature and prospective toxins can be catastrophic for the future. Science can understand the environmental falls of current-day technology, but only with time and by dealing with the consequences now. The cloud is on the cusp of being at the forefront of all

business infrastructure. However, the environmental impacts of the cloud are only starting to gain minimum awareness now. The true power that data centers generate is unprecedented compared to other modern technologies, and the booming expansion further raises the uncertainty of the environmental risks for the cloud.

The cloud has taken over the digital world, with its data centers dominating the physical world. Data centers are now as common as modern utilities such as power plants and are rapidly expanding in construction in metropolitan areas like Northern Virginia in Loudoun County. In Sustainable Cloud and Energy Services: Principles and Practices by Wilson Rivera, he delves into the complexities of sustainable practices within cloud computing and energy services. This source provides valuable insights into the intersection of environmental sustainability and cloud technology, shedding light on the principles and practices that can mitigate the environmental impacts of cloud migration. By exploring strategies for optimizing energy usage, reducing carbon emissions, and promoting renewable energy sources within cloud infrastructure, the book offers and supports the comprehensive framework of environmental ethics for achieving sustainability in cloud computing. The framework's motivation within the cloud emphasizes the "huge amount of reserved yet unused resources by each user of cloud" (Wilson, 2018), where data centers are expected to have instantaneous resource availability. The main benefit of the cloud is that it can scale resources for users dynamically. Because of this, data centers must constantly run with a redundant nature to have this ability. There is no specific pattern, trend, or seasonality in the resource usage of users in the cloud, causing mass energy and resources to be allocated at most times of the day, causing 82% of the infrastructure cost to be mainly cooling and power distribution. In contrast, a fraction is actual computational work for applications (Wilson, 2018). Wilson underscores the importance of integrating sustainability considerations

into the design, implementation, and management of cloud services, emphasizing the need for a holistic approach to environmental stewardship in the digital age. Wilson advocates for a proactive approach to resource prediction to predict future requirements without user intervention. An algorithm to predict resource usage can solve energy usage issues in data centers with goals of efficient capacity planning, reduced energy consumption, and a reduced carbon footprint in switching off unnecessary resource allocation from servers. Drawing upon this source, researchers can gain a deeper understanding of the challenges and opportunities associated with sustainable cloud computing and develop informed strategies for promoting environmental ethics within the context of cloud migration.

In conclusion, the literature review presented here illuminates the critical importance of environmental ethics in guiding the trajectory of cloud migration. As cloud computing rapidly expands in the digital world, the environmental impacts of data centers and energy consumption cannot be ignored. The frameworks provided by scholars such as Gilroy and Wilson Rivera offer valuable insights into understanding and addressing these challenges, where both authors agree on the importance of the environment and the potential grave costs if ignored. Furthermore, they emphasize that there is no clear-cut solution, but being proactive and environmentally conscious can reduce the drawbacks of the cloud. By recognizing the uncertainty inherent in environmental risks and advocating for sustainable practices within cloud computing, researchers can develop informed strategies for promoting environmental ethics within this technological domain. Moving forward, decision-makers, policymakers, and industry leaders must prioritize environmental stewardship in developing and implementing cloud technologies. We can only ensure a harmonious coexistence between technological advancement and environmental

preservation in the digital age through a concerted effort to integrate sustainability into cloud infrastructure.

Balancing Performance and Sustainability: Results and Discussion

The research results demonstrate that balancing cloud migration benefits with environmental sustainability and ethics is feasible through regulatory frameworks of data companies' energy usage, adoption of renewable energy sources, and efficient energy management practices such as AI within data centers, reflecting a commitment to ethical environment stewardship. These findings gain support from case studies of data centers that have innovatively and successfully reduced their carbon footprint and energy consumption drastically. Moreover, analysis of energy reports from data centers reveals their current impact, underscoring the seriousness of potential environmental ramifications. These strategies are grounded in the principles of environmental ethics, which emphasize the moral responsibility to reduce harm and promote sustainability to ensure that the revolution of cloud computing truly aids society digitally and physically. Through vast research within data centers all over the United States and the world, the current model of data centers is not uniform. The difference between them can be the silver light in discovering such balance in performance and sustainability. No singular solution can pave the way for a sustainable cloud future. Instead, a multifaceted approach involving comprehensive, innovative implementations and strict enforcement by regulatory bodies and cloud companies is essential. This study aims to illuminate the overlooked environmental impacts of cloud computing and propose actionable solutions, emphasizing the responsibility towards fostering a sustainable future for the cloud while compromising its capabilities.

Regulatory Limbo of the Cloud

The rapid boom of data centers is a cornerstone of the modern digital age. Nevertheless, it also marks a time when the environmental implications of cloud computing must be considered for nothing like the cloud infrastructure has been seen before. Despite strides towards greener operations, the regulatory framework for these technological energy powerhouses remains lackluster. Data centers are in regulatory limbo, specifically in energy sourcing, leading to oversight over their energy consumption, environmental impact, and credibility of their sustainability. The current regulatory gaps create oversight issues and pose serious ethical concerns regarding accountability and transparency. This lack of regulatory infrastructure makes it difficult to determine the actual environmental footprint of data centers and raises questions about companies' proclamations of 100% renewable energy usage. The transition towards regulating energy sources in data center operations requires significant regulatory hurdles. Lawrence E. Jones, in his exploration of renewable energy integration, underscores the necessity of transparency, accurate accounting, and innovative concepts such as a global power grid to overcome these challenges (Jones, 2014). Embracing such a strategy is pivotal for optimizing renewable energy utilization and ensuring data centers are a force for good now and in the future in achieving environmental ethics objectives.

Jones' perspective is crucial for understanding the challenges and opportunities in regulating the energy sources of data centers in regions like Northern Virginia and Iceland. Each region presents differing scenarios of reliance on fossil fuels versus renewable energy sources. Northern Virginia is one of the most prominent destinations for data centers (Cook & Jardim, 2019), and Iceland is a growing hub for the centers due to its climate (Pedersen, 2019).

Data centers, the foundation of cloud services, are mainly unregulated globally regarding energy consumption and sourcing. This regulatory void poses significant challenges as the exponential growth of cloud usage outpaces environmental oversight. The absence of strict regulations means there needs to be a standardized methodology for verifying the claims of using renewable energy or where they source it. The modern-day data center is no simple building; it is on par with factories and public utilities due to their size, vast energy usage, and now importance to society as seen as a public utility, which is necessary with the internet. The data center bodies are primarily private and cannot be conducted under much environmental regulation because of this. Due to their new nature and lack of regulations, they can be built everywhere. Such has caused severe issues with data centers constructed near residential areas and caused harm with droughts, noise pollution, and unknown potential effects. This scenario highlights the pressing need for comprehensive ethical policies that enforce transparency and accountability in energy sourcing and utilization from data centers.

Many leading cloud companies assert that their data centers operate on 100% renewable energy. However, these claims often need to be held up under scrutiny. The reality is that the energy used by data centers is unethically sourced from the grid, a mix of renewable and non-renewable sources. Such usage is seen in Northern Virginia, where companies like Amazon claim 100% sustainability but keep expanding. Their primary energy source in Virginia is Dominion, and the grid offers few to no renewable energy sources (Cook & Jardim, 2019). There needs to be more than the current regulation of energy sourcing by state to ensure global sustainability, for there is no global regulation if it varies by state. Companies may also purchase renewable energy certificates (RECs) to offset their consumption, but this does not necessarily mean that their data centers are directly powered by renewable sources 24/7. The practice of selling and purchasing

RECs, especially in regions like Iceland, has highlighted the complexity of claiming green credentials. The lack of regulation within said sales raises concerns about the transparency and accuracy of these claims, obfuscating the truth about the environmental footprint these data centers leave. Many companies buy Iceland's certificates, and questions arise about double counting certificates and who is fully sustainable (Adalbjornsson, 2019). Suppose no actions are taken on the current regulatory frameworks. In that case, companies can unethically claim true sustainability and continue to cause harm to said data centers as the cloud migration expands to new frontiers and limits. The doubts about integrity emphasize the need for a more reliable system that ethically reflects the actual use of renewable energy in data center operations. Such clear regulations help display who the actual 100% sustainable companies are.

The current cloud regulation landscape accentuates an urgent call for forming and implementing comprehensive policies to enforce ethical transparency and accountability in data centers' energy sourcing and utilization practices. Such policies would clarify these cloud companies' environmental contributions and verify sustainability claims. Without new policies, the growing deception of true sustainability will continue to grow and allow companies to claim green energy utilization unethically and allow for the continuation of implementing data centers in areas that source their energy unethically, not because they want to but instead are forced too due to the energy infrastructure in areas such as Northern Virginia. Furthermore, there is a pressing need to explore and invest in innovative solutions, such as developing a global power grid that Jones proposes, to facilitate the widespread adoption and effective regulation of renewable energy sources (Jones, 2014). The global power grid Jones alludes to is one where all countries around the world share the same power grid in which countries with more renewable energy sources can fuel others. Such offers many benefits, such as the ability to externally source

energy in surges and low times from renewable sources. Such an idea emphasizes the call for centralized regulation of power grids to data centers; the current system, especially in the United States, being decentralized by states, does not have enough accountability or uniformity. If data centers are regulated, they need to be as a whole and not by case scenario or state, allowing certain areas within the world to continue faking their contributions and masking their harm, defeating the purpose of a universal sustainable cloud system.

Proactive regulations are needed to keep up with the rise of users to ensure renewable sources are available, and the ability to outsource would aid the cloud migration. Establishing environmental sustainability and ethics for the cloud must be done in its entirety. Through such proactive efforts, data centers can become environmentally sustainable and ethical, aligning their operational imperatives with a forced global mandate for ecological preservation and responsible resource utilization with proper accountability. The regulations do not aim to restrict the data center's performance but ensure it is powered cleanly. The call for the regulations is eminent now, and due to the unknown nature of the future ramifications of the cloud on the environment, said regulations need to be proactively monitored. Furthermore, this would make the notion of 100% sustainability believable and quantifiably achievable morally to truly cast the spotlight on sustainable cloud companies, not just those that buy their fake sustainability. In regulating energy sourcing for data centers, a trustworthy, ethical, sustainable future for the cloud can be paved. However, such policies and regulations must be proactively enforced globally to ensure the goal of sustainability is weaved within the frameworks of environmental ethics for the next year of the cloud, let alone months, which can be very different.

The Search for New Renewable Energy Sources

The call for regulating energy sources needs to be fueled by the rise of new ways to adopt renewable energy sources within data centers. Adopting renewable energy sources in data center operations is not merely an environmental imperative but a feasible and innovative solution to the rising demands of the new cloud-based society. The news of Microsoft's Project Natick and Iceland's pioneering use of geothermal and hydroelectric power represent groundbreaking strides toward environmental ethics in technology development. Such innovative ways display that the modern-day confidence of lacking renewable energy sources is not just a hurdle but a doorway to exploring other alternatives that embody an ethical commitment to minimizing the environmental impacts. The successful alternatives in said cases cultivate creativity for establishing new areas for data centers worldwide and the ocean, providing a compelling ethical argument for rethinking how and where data centers are built and emphasizing the importance of integrating environmental values within the cloud's evolution process.

Microsoft's Project Natick is a prominent case study in ethically sustainable data center operations. Natick is an underwater datacenter deployed off Scotland's Orkney Islands that leverages the natural cooling properties of the ocean, significantly reducing the energy required for cooling. Powered by 100% renewable energy from wind and solar sources, Project Natick demonstrates the practicality and reliability of underwater data centers and their performance and environmental benefits. Such underwater centers benefit from natural cooling and greater energy efficiency and offer enhanced connections to coastal regions (Roach, 2020). This innovative project demonstrated that underwater data centers could outperform their land-based counterparts in reliability, for the hardware after two years underwater was eight times more reliable than equivalent servers running on land. Questions arose about whether the heat dispersion from the

center underwater would cause environmental impacts. However, the water discharged was a "fraction of a degree warmer than what comes in from the ambient ocean" (Judge, 2021). Such discovery led to no local severe effects and placed them in strategic areas of persistent currents to ensure such. Adding on, the location of the centers by the shoreline allowed for better accessibility and efficiency to cloud users by the sea, furthering the point in how innovative ethical solutions to new renewable energy sources can improve the cloud's benefit without the cost of operational performance but rather enhance it. The project's success in reducing operational failures due to stable undersea conditions offers a promising path for enhancing data center reliability and sustainability on a global ethical scale. Adding on the minimal waste of energy cooling gave the center an excellent low power usage effectiveness (PUE) of 1.07. Project Natick displays the synergy between ethically innovative deployment strategies and environmental stewardship.

Iceland stands at the forefront of sustainable data center development, driven by its unique climate and abundant renewable energy resources. Data centers in Iceland, like those operated by Verne Global and Etix Everywhere Borealis, utilize geothermal and hydroelectric power to achieve near-complete sustainability. The cool Icelandic climate allows for natural cooling throughout the year, drastically lowering cooling costs and enabling operations with a remarkably low PUE of 1.03 (Pedersen, 2019). This sustainable model caters to high-demand sectors such as bitcoin mining and cloud computing and sets a benchmark for environmental stewardship in the tech industry. The country's commitment to green energy has attracted international companies, including tech giants like Facebook and TikTok, to establish their data centers in Norway. Such migration to Norway data centers is no mere trend, with an estimated rise of 85% in electricity consumption in Denmark's business sector (Pedersen, 2019). This

approach exemplifies environmental stewardship and positions Iceland as a prime location for data-intensive industries seeking green solutions. Iceland's ability to capitalize on its environmental factors showcases its ability to ethically promote the cloud's growing nature by being environmentally conscious and offering its sustainable capabilities to data companies globally. Since data centers serve a global cloud, they can be placed anywhere, and discovering new locations to add to the existing system not only boosts the cloud but can also foster new ethical sustainability sources, allowing all cloud companies to benefit from the expansion into areas businesses would never deem as profitably operational nor successful.

The case studies from Microsoft and Iceland illuminate the crucial path for the broader adoption of renewable energy in data centers globally. They highlight the creative intuition and necessity of overcoming regulatory and logistical challenges to facilitate this transition, urging the development of new frameworks that encourage using sustainable energy sources. Such innovative cases exemplify that the bridge between ethical sustainability and cloud performance does not need to be at the cost of one but can pivot to benefit each factor with creative thinking and innovation. The reasoning behind showcasing the cases is that the primary purpose of data centers is to cool them. If that factor was removed, the focus could be on other aspects to improve, such as actual computation to increase the cloud's efficiency, connectivity, and accessibility, as found within Natick. In incorporating these experiences with the research, the need for a combination strategy becomes clear. It involves adopting renewable energy sources and rethinking data center design and location to optimize natural environmental conditions and energy usage. The implementation of using the environment as an advantage to cool the cloud technology reflects an ethical approach to the current energy sources dilemma. The success of these diverse data centers promotes creativity around the globe in how the cloud can be

supported ethically and implemented in the future, turning towards new regions and areas to expand data centers. Ensuring the cloud's foundational data center infrastructure operates sustainably and ethically as the digital age expands is paramount. Through the discoveries from Project Natick and the Icelandic model, the industry can make significant strides toward achieving global environmental sustainability objectives within environmental ethics, setting up new means and models of green cloud computing.

While these case studies provide compelling evidence of the feasibility and benefits of using new forms of renewable energy sources within cloud data centers, they also raise ethical questions about the sincerity of such initiatives. Only time will tell if these environments and locations will continue to be capitalized upon and expanded upon in future data center construction. Concerns and suspicions arise for whether projects like Natick could be perceived as unethical publicity stunts – efforts by corporations to appear environmentally conscious without a genuine commitment to sustainable practices. Such is to distort society's view on the progress of weaving environmental ethics and sustainability into their cloud infrastructure. This view necessitates vigilant monitoring and continuous evaluation to ensure such project initiatives genuinely embody ethical practices and contribute to a sustainable future. Expanding into these new regions of renewable energy sources must be continued and monitored, for the environment is changing every year, with global warming concerns impacting cold areas like Iceland with its tundra biome and even sea levels potentially impacting underwater data centers. Such impacts can lead to environmental damages that cannot be predicted nor quantized as the global climate evolves to levels never seen before around these newly fueled data centers. Integrating new renewable energy sources into the current cloud computing infrastructure with the success of Project Natick and Icelandic data centers demonstrates that it is feasible and beneficial with the

intersection of technology and environmental ethics. However, to maintain the ethical integrity of such initiatives, it is crucial to continuously develop new frameworks that encourage adopting these sustainable practices and monitor them to ensure these are not mere corporate greenwashing but rather a steadfast commitment to environmental stewardship. The future of data centers does not need to undergo vast remodeling to accommodate increased sustainable usage; perhaps they need to be relocated and reimagined, fostering a new look to cloud infrastructure.

Pioneering Energy Management Systems

The hardware within data centers is top of the line; they are designed for peak performance, especially in hyperscale centers from the largest cloud providers such as AWS and Facebook. However, the call for peak performance is a double-edged sword, requiring energy usage on scales never seen before. The need for the cloud to be fully scalable with data ready always requires data centers to be fueled around the clock 24/7, accounting for most energy usage with cooling. The call towards finding sustainable solutions to energy usage within data centers has led to the adoption of advanced energy management practices, notably Google's AI cooling system and the integration of Battery Energy Storage Systems (BESS). Integrating these innovative management systems reflects the ethical responsibility in environmental management. These technological revelations revolutionize how data centers manage and operate energy consumption by providing metrics on energy usage. The increased adoption of such techniques and algorithms aids the cloud's environmental sustainability path ethically, for these technological revolutions are not mere trends but fundamental steps of taking cloud computing to the next level environmentally, ethically, and sustainably.

Google's AI cooling framework is a stunning example implored in data centers to promote energy efficiency and environmental sustainability. Google's framework leverages machine learning to analyze cooling sensors and electrical equipment data. DeepMind's framework can predict and implement the most effective cooling strategies. The algorithm analyzes snapshots of the data center's cooling system, predicts optimal energy efficiency actions for future consumption, and verifies the results to be implemented safely so as not to cause downtime for servers. This algorithm reduces the energy used for cooling by an astonishing 40% and a 15% reduction in the data center's overall Power Usage Efficiency (PUE) (Okyere, 2021). Such achievements highlight the potential environmental and economic benefits of integrating AI into data center operations, making a compelling case for broader adoption across the industry. AI is a growing field and, with more innovation, can aid energy usage in more aspects of data centers to ensure a balance between performance and sustainable energy use ethically in reducing the sheer power demand of the cloud. AI is not only a helpful tool but a customizable technology that can be perfectly conformed and utilized to ensure peak performance and energy usage from data centers.

The introduction of Battery Energy Storage Systems (BESS) into the data center energy crisis is a compelling solution for the challenges posed by the lack of renewable energy and the imperative for continuous power supply always to keep data on standby. BESS are battery units that can store energy from renewable sources like solar or wind, ensuring a dependable, clean energy supply, even during peak times (Nieto, 2023). BESS enhances the flexibility of data center operations and aligns with sustainability goals by reducing reliance on fossil fuels and facilitating a transition to cleaner energy sources. The batteries work by being modular and easily charged to power the centers with clean energy, highlighting sourcing renewable energy sources

ethically. Such eliminates one of the challenges in fueling data centers with renewable energy, but they still need to be fueled from areas that have said clean energy available; however, they now can be transported to areas aiding the disconnection between areas of non-renewable sources due to their modular and portable nature. BESS's versatility also aids its capabilities when integrated with an Energy Management System (EMS). BESS can provide valuable data and analytics, enabling data centers to optimize energy demand and efficiency. In combining the two cutting-edge technologies, BESS and AI, data centers can understand their energy usage better with data, which can be further implemented to build new solutions and algorithms for energy usage. The fusion between such new technologies and the cloud computing infrastructure demonstrates bridging gaps in renewable energy integration.

New technology and algorithms are being discovered daily in this rapid digital age. With their adoption of the current system, the path to a sustainable cloud future lies within incorporating new technological feats rather than ignoring them. Although technology such as AI and BESS need to be tailored and customized for each data center, the result noted from the example cases could be critical to solving issues of managing energy usage. The adoption of these technologies reflects the initiative of cloud companies to reduce their environmental impacts within their digital infrastructure. They further signify how addressing the growing energy requirements can adhere to the framework of environmental ethics and sustainability and even promote the capabilities of the cloud.

By embracing new technology and innovating it with others, data centers can significantly ethically contribute to global sustainability objectives by relying on technological advancements and ensuring that cloud migration can be supported in compliance with a healthy environment and improved. The constant inclusion of adapting and conforming new technology

also promotes the cloud's performance, taking it to new limits and discovering new capabilities. Ethically, combining the new feats of AI and BESS technology within data centers supports the broader goals of sustainable development by ensuring that technological advancements contribute positively to the environment rather than inflaming existing challenges. The adoption within data centers is a testament to the cloud industry's testament to lead in environmental ethics. These technologies are not just flashy trends but rather crucial components of a sustainable cloud future that align operational goals with ethical responsibilities. It is ethically essential to ensure such adaptive progression is continued and not dismiss new fundamental tools that arise that can be tailored to the cloud infrastructure. For cloud computing to remain a driving force in innovation and efficiency, it must champion the principles of environmental stewardship. By moving forward and ensuring these ethical practices are maintained, expanded, and intertwined into all facets of the cloud infrastructure, the cloud can display how persistently adapting and utilizing new technologies as more than trends but rather fundamental tools that will reinforce the role of technology as a force for good in the battle against environmental degradation in the ever-evolving digital age. An ethical, sustainable cloud future is possible if new technological revolutions are responsibly incorporated rather than utilizing them for the trend; perhaps a green cloud future can reside in the present if companies look beyond the flashy nature of current technological trends now and see the true potential they hold to not only reimagine the cloud infrastructure operations but aid their growing usage impacts on the environment.

The Final Frontier in Cloud Sustainability: Limitations and Future Aspirations

The limitations of this project are that it only has some of the complete energy usage metrics reports and operational data from the data centers around the globe. Such is due to the lack of regulation and privatization of the current-day cloud computing infrastructure. Adding on, many of the environmental impact reports were limited due to the newfound nature of data centers, and only in recent years have articles and journals been posted on their ramifications, and more long-term effects are yet to be seen. I would love to continue this research, for the cloud is no mere phenomenon but a revolutionary application to all digital structures within businesses and society. Future research would explore in greater depth the long-term effects of data centers and analyze how data centers have aged over time. Furthermore, exploring other policies that have been placed intact on energy usage within other new prevalent technical fields, such as electric vehicles, to see other technologies' paths with environmental sustainability. In addition, interviews with industry workers and experts implore deeper insights into the opportunities and challenges in achieving a sustainable cloud in data centers in person.

Forging a Sustainable Path for the Future of Cloud Migration

This research project on harmoniously balancing cloud migration benefits with environmental sustainability showcases that advancements in applying environmental ethics are not only possible but imperative for the future development of cloud technology. The path of action includes integrating regulatory frameworks of cloud energy usage, adoption, and innovation of renewable energy sources, and implementing advanced energy management practices utilizing cutting-edge AI and BESS technology. Each step individually does not offer the key to sustainability, but the combination offers an excellent approach with the proposed

components' synergy. Through imploring environmental ethics within cloud computing and highlighting innovative case studies of data centers around the globe, this research highlights the need for a multifaceted solution that implores techniques and technology worldwide, ensuring the necessity of embedding environmental ethics within the core of cloud computing. In working with and incorporating newfound feats of sustainability discovered around the globe, the cloud can aid society more efficiently and powerfully, all while not being imperative to the environment. The key takeaway within the research is that achieving sustainability in the cloud is within reach, only requiring dedicated and combined ethical efforts across technological and regulatory landscapes.

Data centers are a new phenomenon that no one has been able to perfect in its fully sustainable longevity; in being creative and resourceful, the transition to a green cloud does not have to be an impossible task. Not all data centers are created equally, and with a proactive effort from the industry and governing bodies, the impact of all data centers can be reduced. New technology and innovative solutions with ethically driven efforts can be combined to facilitate excellent cloud implementation. It is vital to embrace a proactive, cumulative approach to innovation and creativity within the cloud to address environmental sustainability challenges. By expecting potential ramifications, implementing forward-thinking policies, adopting new technologies, and leveraging newfound renewable energy sources, diverse solutions can exist that safeguard our environment before problems arise. This proactive stance enforces that sustainability and environmental ethics are woven into the foundation of cloud infrastructure rather than being a reactive measure to future crises. Furthermore, such energy solutions solve unethical sourcing issues and provide newfound performance within the cloud, setting a new standard for how technological advancements should evolve within an ethical framework. The

evolving cloud infrastructure still must be monitored vigilantly in incorporating the proposed solutions, ensuring that the frameworks, new renewable sources, and incorporation of new technologies are ethically persistent and adaptive to the ever-changing landscape of the new digital world and physical environment. Overall, this research calls for prioritizing environmental and ethical sustainability within the cloud's evolution, ensuring that new revolutionary technology progresses responsibly and sustainably to aid society in the future rather than be a dormant issue society must face later.

Sources

Adalbjornsson, T. (2019, June 18). *Iceland's data centers are booming—here's why that's a problem*. MIT Technology Review. https://www.technologyreview.com/2019/06/18/134902/icelands-data-centers-are-booming-heres-why-thats-a-problem/

Cook, G., & Jardim, E. (2019). Clicking Clean Virginia. In *Greenpeace Reports*. https://www.greenpeace.org/usa/reports/click-clean-virginia/

Gilroy, J. M. (Ed.) (2018). Environmental Risk, Environmental Values, and Political Choices: Beyond Efficiency Trade-offs in Public Policy Analysis. Abingdon, Oxon: Routledge, Taylor & Francis Group.

Jones, L. E., Ebook Central - Academic Complete, Knovel, A., E. &. P. E., & O'Reilly Online Learning: Academic/Public Library Edition (2014). Renewable Energy Integration: Practical Management of Variability, Uncertainty and Flexibility in Power Grids. Amsterdam: Elsevier, AP.

Judge, P. (2021, January 5). *Project Natick: Microsoft's underwater voyage of discovery*. Www.datacenterdynamics.com. https://www.datacenterdynamics.com/en/analysis/project-natick-microsofts-underwater-voyage-discovery/

Monserrate, S. G. (2022, February 14). The Staggering Ecological Impacts of Computation and the Cloud. The MIT Press Reader. https://thereader.mitpress.mit.edu/the-staggering-ecological-impacts-of-computation-and-the-cloud/

Nieto, C. (2023, September 21). *Keeping the lights on for the modern data center*. DataCenterDynamics. https://www.datacenterdynamics.com/en/opinions/keeping-the-lights-on-for-the-modern-data-center/

Okyere, E. (2021, January 24). *How DeepMind made Google energy efficient*. Nural Research. https://www.nural.cc/deepmind-ai-framework/

Pedersen, N. (2019, September 23). *Iceland is the coolest location for data centers*. IBM Digital Nordic. https://www.ibm.com/blogs/nordic-msp/iceland-data-centers/

Rivera, W., SpringerLink (Online service), & Ebook Central Sustainability eBook Subscription (2018). Sustainable Cloud and Energy Services Principles and Practice. S.l.: Springer International Publishing.

Roach, J. (2020, September 14). *Microsoft finds underwater datacenters are reliable, practical and use energy sustainably*. Source. https://news.microsoft.com/source/features/sustainability/project-natick-underwater-datacenter/