Seminar Report

Sustainability For Data Centers

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Abstract

The enormous growth of digital data and increasing demand for computational power has resulted in a significant rise in the number and scale of data centers globally and growing importance of sustainability in data centers. The amount of energy consumed by data centers also underscores the need for eco-friendly sources of energy to sustain data centers seeing the threat which non-renewable energy sources energy sources poses to our environment resulting from carbon footprint emitted from the use of these non-renewable energy sources. This document delves into key metrics for sustainability of data centers, discusses what components of data centers constitute huge power draw, existing challenges associated with powering data centers and challenges in embarking on green energy sources for ensuring consistent supply of energy to these facilities. Furthermore, it delves into ways to maximize energy efficiency in data centers, and some means to ensure uninterrupted power supply to these facilities. Finally, it elaborates on innovative technologies which enhance efficiency of data centers, and highlights the significant benefits of relying on eco-friendly energy sources as a means of sustaining data centers, not only to mitigate environmental impact, but also for long-term viability, a critical aspect that cannot be overemphasized.

Contents

List of Figures

1 Introduction

Data centers play a significant role in digital infrastructure, serving as a facility that houses IT infrastructure for building and delivering applications and services, storing, processing and managing data associated with those applications and services. As stated in the book written by Corey Gough et al., titled 'Why data efficiency matters', "data centers are the nucleus of digital economy" and "the information factories that shape our modern experience"[1]. Sustaining a data center is a crucial aspect of the IT industry, and with an increased need for a greater number of data centers comes increased efforts to make them sustainable. Energy consumption of data centers draws global attention to data centers because of the huge amount of electricity they consume. The enormous energy consumption of data centers has been a growing concern and an increased need for data centers arises because of an increase in demand for digital services, cloud computing, exponential rise in data-intensive applications, continual dematerialization of goods, and growth of the economy e.t.c. Internet of things is a major contributing factor to the exponential increase in need for more data centers[2].

Sustainability of Data centers, refers to when the energy powering data centers is made to run uninterrupted. Power outage in data centers is disastrous and should be avoided completely. As a result of the huge capital required to get the data centers running again, and the significant consequences on the services they supply. The necessity of sustaining Data centers is crucial for Business Continuity purposes, Data integrity and availability, preventive loss due to downtime. The need, therefore, for the sustainability of Data centers cannot be overstated.

Asides being an energy-intensive infrastructure, they are highly capital intensive. Power outage in data centers can occur in data centers because of insufficient backup power, cooling failures, cyber security threats, Human errors, among other factors. Commonly used existing solutions to ensure backup power in case of electrical outages include Uninterrupted Power Supply and Diesel Generators. Some more advanced improvements to these solutions to power outage in data centers include but not limited to; Onsite-Power generation, renewable energy sources which include Green Hydrogen, Solar Power, and the use of Data Center Heat.

The key metrics to sustainability of data centers and challenges as well as the benefits associated with some means of ensuring uninterrupted power supply to data centers, will all be addressed in more detail further in this report. Deploying these cutting-edge methods to power data centers guarantees the prevention of power failures in the facility.

2 Energy Consumption in Data Centers

The primary element influencing efficiency in data centers is “scale”, which is attributed to the substantial energy consumption by these facilities. Scaling up a data center involves augmenting the existing data center infrastructure by adding more CPU, memory, or I/O devices, or upgrading to a larger and more powerful server. The size and configuration of hardware in data centers vary, contingent on the workload they handle, and companies may employ different types, based on their business requirements. Data centers demand significant electrical energy for their operations, with considerable portion attributed to sustaining servers. According to C and C Technology Group[1], typically, they consume about 1000kWh per square meter, a magnitude approximately ten times greater than the energy consumption of an average American household. According to the US Department of Energy, “ the largest data centers with tens of thousands of devices require over 100MW of power, which is enough to power approximately 80,000 households”[8].
A data center can vary from a few set up of servers in a room, to extensive structures that span hundreds of thousands square meters, housing tens of thousands of servers and additional hardware.

Various types of data centers include Colocation facilities, Enterprise data centers, and Hyperscale data centers. The latter, designed for hyperscale computing and essential for cloud and big data storage, typically encompass at least 929 square meters, and have more than 500 cabinets and 5000 servers operating on an ultra-high-speed network[9]. Numerous Hyperscale data centers are managed by leading cloud service providers such as Amazon Web Services (AWS), Google Cloud Platform, IBM Cloud, Microsoft Azure, among others. According to Enerdata IEA, Data centers use more electricity than entire countries.
Characteristic of large-scale data centers is their demand for tens of megawatts of electrical power, equivalent to the energy required to sustain a small city [2]. This substantial energy consumption is a key factor drawing attention to data centers.

See diagram below for further clarification[18].

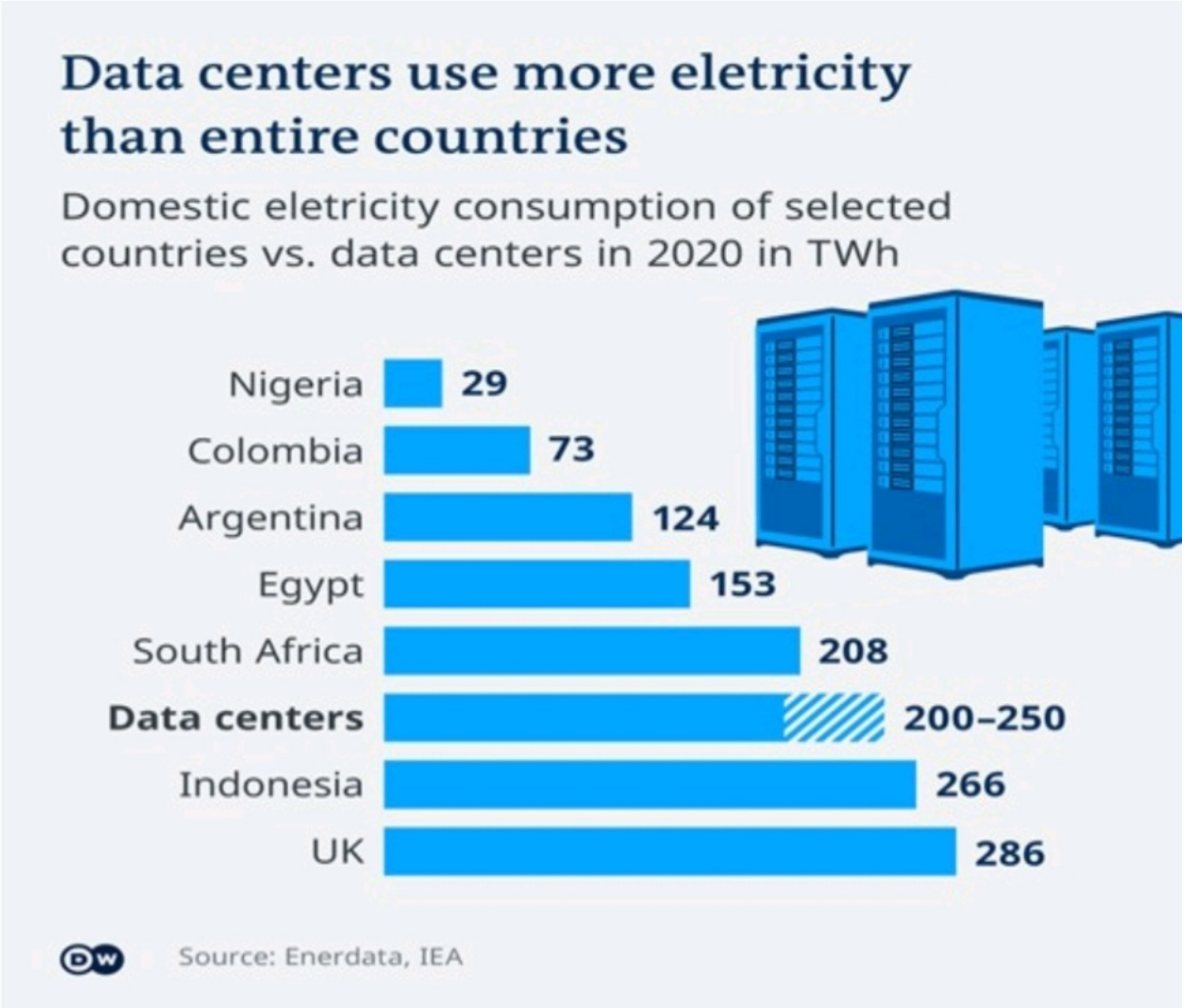

Figure 1: Domestic Electricity Consumption Of Selected Countries vs.Data Centers In TWh

3 Importance of Sustainability For Data Centers

The goal of a data center is to meet the computational needs of the organization. computational needs refer to physical and financial needs of the organization. Forecast by B Marcus Law, December 30, 2022 for 2023 says "Data centers are estimated to be responsible for up to 3% of global electricity consumption today and are projected to touch 4% by 2030" [10].

See below, a diagram for illustration [19].

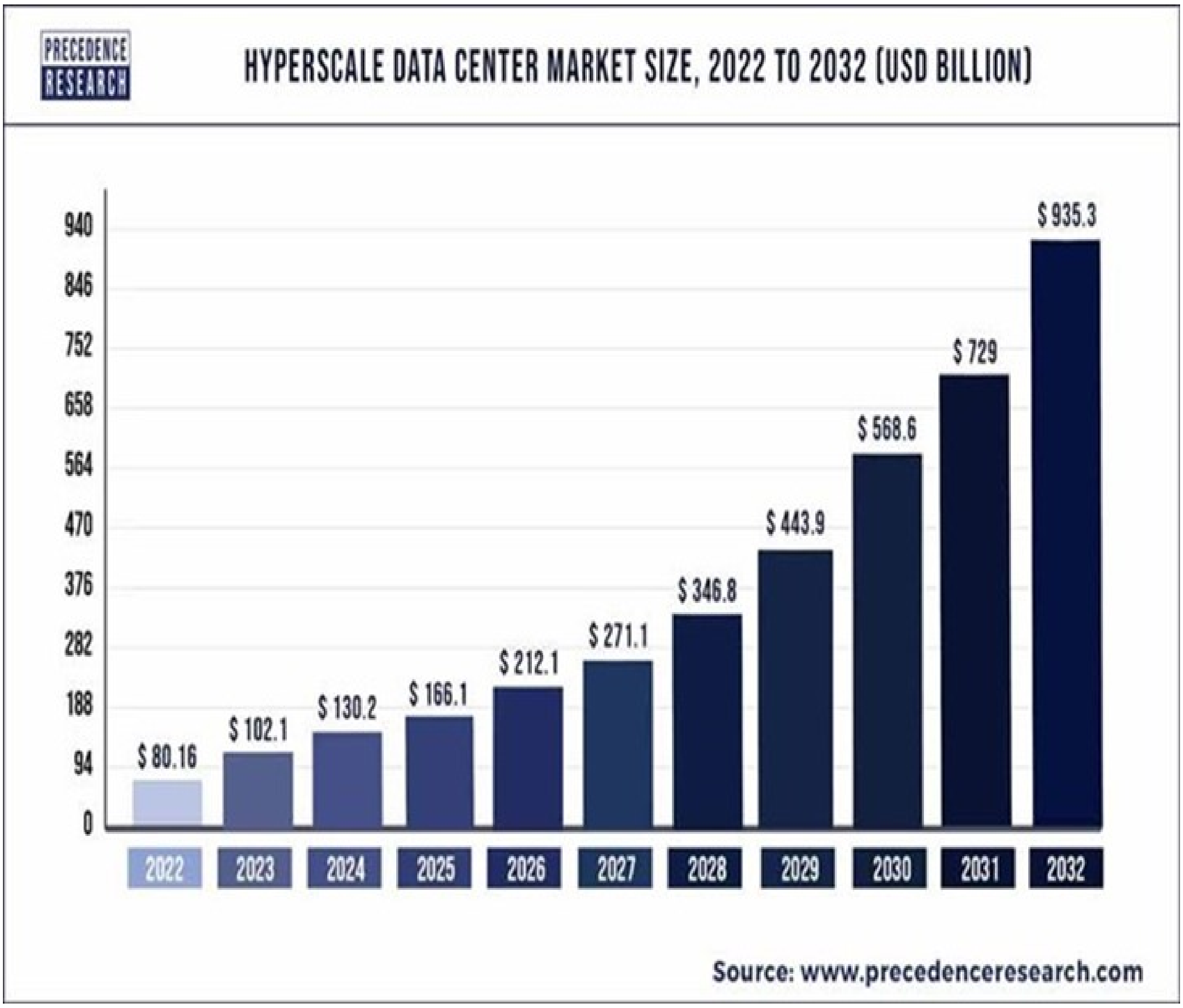

Figure 2: Hyperscale Data Center Market Size From 2022 To 2032.

Sustaining a data center is ensuring there is no power outage in the data center. It is crucial to meeting the organizational goals financially because power outage in a data center has great consequences which are inconvenient for the administrators, since it can cost huge expenses to get it running again.Recent survey from Uptime Institute Global Data Center Survey 2023, reports that 1 in 6 data centers that suffered a major outage incurred over 1 million.Unplanned data center outages are frequent events, occurring more often than they ideally should, considering the significant repercussions that power interruptions can impose on the administrators of such facilities. Preventive measures ought to be put in place to ensure uninterrupted power supply.

4 Causes of Power Outages in Data Centers

Some causes of data center failure include [11];

- Insufficient backup power.
- Cooling failures.
- Cyber security threats.
- Human error etc.

Insufficient backup power: Power outages can occur when backup systems like generators and UPS (Uninterrupted Power Supply) systems, such as batteries, fail. Generators may cease running after a few hours, and there is a potential risk of them failing to start. Additionally, when the UPS system reaches the end of its runtime, it can lead to complete power outage in data center.

Cooling failures: Data centers can experience failures due to overheating. When the equipment reaches excessively high temperatures, it automatically shuts down to prevent damage, resulting in downtime. Overheating is often exacerbated by inadequate circulation of cold air through the cabinets and the loss of cooling system redundancy.

Cyber security threats: A prevalent form of cyber-attack is the use of malicious software, commonly referred to as malware, which can wreck havoc in data centers. For example, the reported cyber-attack on the Power grid of Ukraine in 2015, attributed to Russia, resulted in power outage affecting more than 200,000 people for a duration of 1-6 hours[4]. Similarly, cyber-attacks on data centers have the potential to disrupt power systems. Hackers may employ phishing techniques, a procedure that could be utilized to induce power outage in data centers.

Human error: Human error as reported by Uptime Institute in a 2021 survey [6], is frequently cited as a factor contributing to power outages in data centers. The survey revealed that 48% of the outage in power were attributed to the actions of data center staff, specifically instances of failure to follow procedures. The two primary causes highlighted in the survey were failure to adhere to procedures and having incorrect processes and procedures. Furthermore, when some personnel are not properly trained to operate data centers, huge mistakes in running operations can occur, leading to disruptions power in data centers.

5 Data Center Components And Their Power Consumption

See below, a diagram that illustrates percentage allocation of where data center power goes [20].

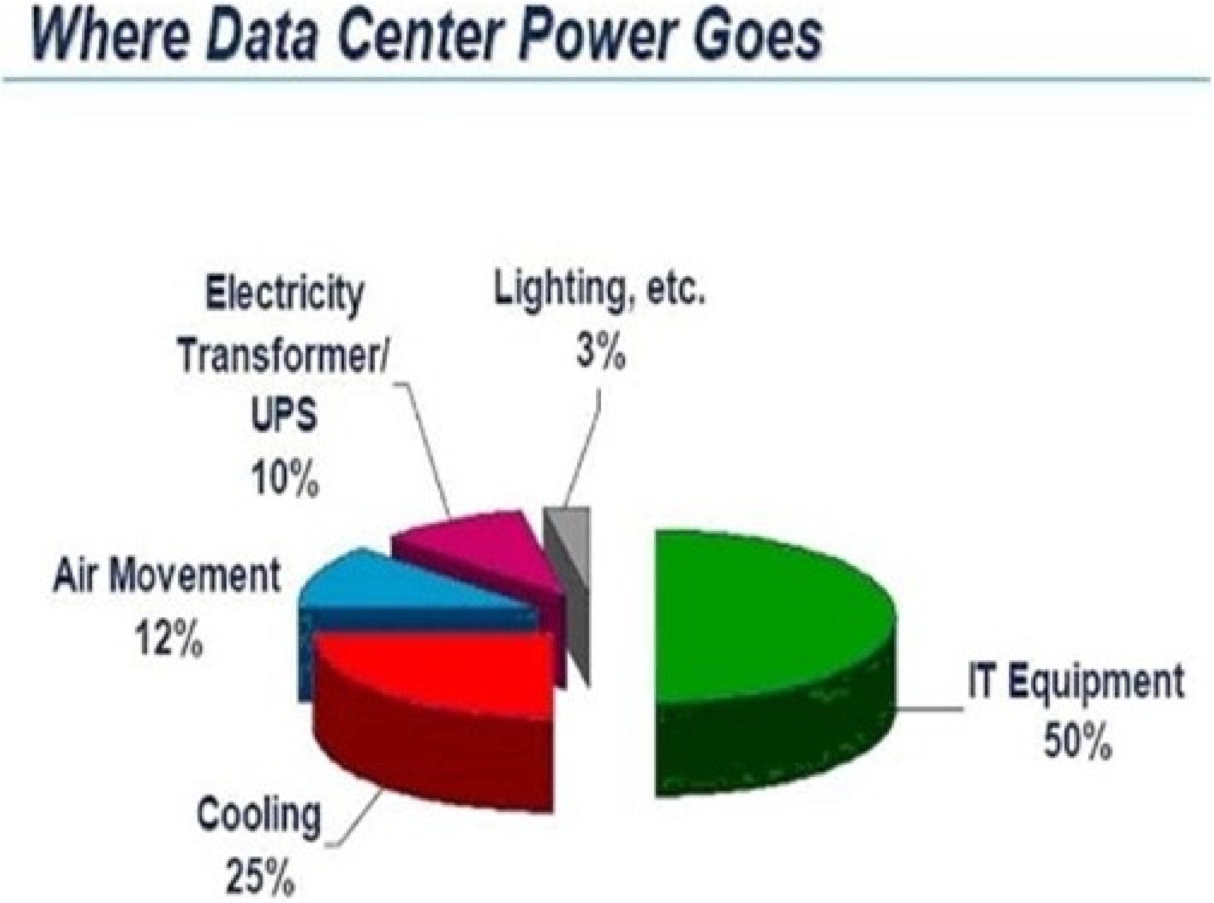

Figure 3: Percentage Estimate Of Where Data Center Power Goes.

Servers: Rack servers are one of the two dominant energy-draining component in data centers [3] and are one of the most important structures of a data center. They constitute a significant power draw[12]. The monitoring of power consumption involves segmenting it into IT tasks such as server, power, and non-IT tasks, including lighting and cooling. If the power requirements remain consistent for IT essential functions, efforts should be made to identify opportunities for to reducing power consumption in non-IT tasks.

Cooling Systems: High density racking can increase the need for cooling, resulting in the use of more power. Hence, the need to balance efficient use of space while considering the impact that the infrastructure can have on things like cooling and power consumption. Cooling systems are also a major energy draining facility in a data center [5]. Effective management and proactive preventive measures, play a crucial role significantly reducing outages and optimizing the productivity of data centers Depending on the climate, in certain scenarios, allowing cool outdoor air into the environment can aid to reduce power draw from cooling systems.

6 Metrics for Sustainability in Data Centers

In recent years, there has been a development of various metrics aimed at quantifying and comparing the effectiveness and efficiency of data centers. These metrics serve the purpose of assessing individual components of the infrastructure, including cooling, IT, and power supply, or evaluating the data center as a holistic entity. They encompass aspects such as overall energy and water consumption, greenhouse gas emissions, and the efficiency of subsystems. The primary objective of metrics is to provide a descriptive representation. Inadequately defined metrics can hinder business innovation and obstruct the attainment of environmental sustainability goals [24]. Power Usage Efficiency (PUE) has emerged as the predominant and extensively employed metric for evaluating the performance of data centers. PUE is calculated by dividing the total power input by the energy consumed by computer servers. A PUE of 1 signifies an optimal scenario where all energy is utilized by computer servers. The global average PUE is approximately 1.89, and Google stands out as a leader with an impressively low PUE of 1.12 [25].
Some categories of sustainability metrics for data centers include:

Energy Efficiency Metrics: The energy efficiency of a system is quantified as the ratio of the useful work performed by the system to the total energy supplied to it. In the context of data centers, energy efficiency pertains to the effective work executed by distinct subsystems. The Green Grid consortium has introduced metrics such as Partial Power Usage Effectiveness (pPUE), a derivative of PUE, and Data Center Infrastructure Efficiency (DCiE) [25], which assesses data center efficiency by correlating power consumption with IT equipment functionality. PUE and DCiE provide insights into overall data center efficiency, while pPUE specifically gauges the energy efficiency of a designated zone within a data center. The consortium has also proposed metrics including Carbon Usage Effectiveness (CUE), Water Usage Effectiveness (WUE), and Electronics Disposal Efficiency (EDE) to gauge the CO2 footprint, annual water consumption, and disposal efficiency of data centers, respectively. SPUE metrics, grounded in principles akin to the PUE metric, offer a specialized assessment of the energy efficiency of servers within data centers. Noteworthy among the metrics is DPPE, which amalgamates four distinct metrics-DCiE, Green Energy Coefficient (GEC), IT Equipment Energy (ITEE), and IT Equipment Utilization (ITEU). This composite metric provides a comprehensive evaluation of data center performance in relation to energy consumption [24].

Cooling Metrics: The management of heat generated by IT equipment within a data center is imperative to sustain optimal operational performance. Consequently, cooling systems assume a crucial role in the overall functioning of data centers [24]. The intricate integration of HVAC (Heating, Ventilation, and Air Conditioning) systems is designed to establish and maintain optimal conditions within the computing environment, thereby ensuring the longevity, scalability, and flexibility of server infrastructure.

Performance Metrics: : The assessment of a data center's performance encompasses the overall efficacy of the system, considering factors such as throughput, response time, and availability.. Assessing the performance of a data center presents challenges, including the differentiation of significant workloads, accounting for measurement overhead, addressing energy distribution losses, and gauging energy consumption across various levels of the data center [25], [24]. Accurate measurement of performance and productivity is paramount, given that suboptimal performance carries operational and financial consequences for a data center.

Financial Impact Metrics: Financial metrics provide insights into financial risks associated with data center operations. This includes evaluating the impact of potential disruptions, understanding the cost of downtime, and implementing strategies to mitigate financial risks. While organizations often leverage non-financial operational metrics for diverse objectives, excluding budgeting and project measurement, an exemplary metric in this context is Total Cost of Ownership (TCO). TCO, a paramount cost determinant for IT and a significant expenditure for ancillary units such as cooling and lighting, plays a pivotal role in facilitating informed decision-making and effective demand management [24]. Capital expenditure and operational expenditure distinctly delineate the funds required for acquiring physical assets and the costs associated with operationalizing them.

Thermal and Air Management Metrics: Thermal and air management metrics serve to quantify the environmental conditions within a data center and analyze the airflow dynamics, tracing the path from cooling units to vents [24]. These metrics are instrumental in diagnostic assessments, offering insights into factors such as the extent of re-circulation and bypass air. Primarily hinged on the correlation between airflow rate and ambient temperature, these metrics are subject to influence from internal parameters and geographical location. Parameters such as temperature, humidity, dew point, and heat flux are employed to prevent overheating, maintain optimal humidity levels, assess the current state of the cooling system, and inform decision-making processes. Air management metrics, in particular, focus on evaluating the efficiency of airflow and the segregation of hot and cold air streams.

Green Metrics: The carbon footprint and greenhouse gas emissions are pivotal considerations for the future of our society and are increasingly falling under governmental regulations and taxation. Consequently, the environmental sustainability of a data center, often referred to as its "greenness," is gaining heightened significance and rightly so[24]. Green IT contributes to environmental well-being by enhancing energy efficiency, reducing greenhouse gas emissions, utilizing renewable resources, and promoting practices such as reuse and recycling.

Security Metrics: Security metrics serve as quantitative indicators assessing the efficacy of deployed security strategies. Defined as a system of interconnected dimensions compared against a standard, a security metric enables the quantification of the degree of freedom from potential damage or loss resulting from malicious attacks. In the context of a data center, fundamental security objectives encompass authentication, authorization, and data protection [24]. Data centers are purposefully engineered to withstand a spectrum of threats, ranging from hacking of data, through malicious software to natural disasters. Upholding high-security standards necessitates adherence to a set of practices and guidelines.

7 Maximizing Efficiency/Uptime of Data Centers

Maximizing Efficiency/Uptime of Data Centers Power and Performance Util- ity costs are a major concern for most data centers. According to Packer- Power, in the document 'Guide to Data Center Monitoring', year 2023 it is stated that power constitutes 70 percent of the total operational cost (TOC) of a data center. Maximizing uptime and minimizing downtime caused by factors such as power failure is crucial. A well-known strategy to prevent failures resulting from power outages is to invest in an uninterruptible power supply (UPS).

8 Ways to Supply Uninterrupted Power to Data Centers

Some ways to ensure energy efficiency in data centers [13] include;

- Onsite-Power generation
- Green Hydrogen
- Solar Power
- Use of data center heat.

On-site Power generation:
On-site power generation in data centers refers to the production of electricity within the data center facility [14]. This is accomplished through various means such as solar panels, wind turbines etc. Onsite generation can be designed to use renewable energy sources, reducing the environmental impact of data center operations. This aligns with sustainability goals and helps mitigate the carbon footprint associated with traditional grid-supplied power. This means of producing electricity which is independent of external power grids reduces the risk of disruptions due to grid outages, ensuring continuous operation critical for data center functions. The implementation of on-site generation, encompassing gas-fired reciprocating engines, micro-turbines, and fuel cells, enhances overall efficiency by enabling the efficient capture and utilization of waste heat [26].
In certain scenarios, the excess and redundant capacity of the on-site generation facility can be strategically utilized to vend electricity back to the grid, thereby mitigating the capital cost of the generation plant. This approach not only offers an alternative to grid-supplied power but also yields waste heat, which can be harnessed to fulfill proximate

heating requirements. By producing electricity locally, financiers of data centers can potentially avoid peak demand charges and have more control over the cost of energy, contributing to overall cost savings. The waste heat which is produced can be utilized for space heating, water heating, or cooling through technologies like absorption chillers, improving overall energy efficiency. Potential revenue from selling excess power back to the grid, can lead to cost savings over time.

Pros:

- Serves as an emergency backup during power outages.
- Increased energy efficiency and maximized uptime.
- Promotes technological advancement in renewable energy.
- Provides improved energy density, reduced transmission line losses, decreased conversion losses.
- Lowers operating cost.

Cons:

- Very costly.
- Resource availability poses barriers to success.
- local market supply and monopolies are challenges.

Solar Power: Solar power is obtained when sunlight is converted to electricity, and this is achieved either directly using photovoltaics(PV), or indirectly making use of concentrated solar power(CSP). Solar energy can also be collected by Parabolic Trough Collectors(PTCs) and bifacial PV modules to convert it to electrical power and heat. This generated electrical power is used to power the data centers as a back up power to hydrogen supply for sustaining the data centers. centers need consistent and reliable supply of energy, and since Solar energy alone cannot provide an uninterrupted power supply to data centers due to its intermittent supply, reliable power integration can be achieved by integrating it with some other renewable energy produced by wind turbines. combination of solar energy with wind energy will ensure continuous energy supply to a data center and guarantee that energy is always supplied to the data center [26].

Pros:

- According to the U.S. National Renewable Energy Labs (NREL), connecting solar production to systems in data centers improves generator runtimes, maintains uptime with batteries and solar in the event of fuel exhaustion.
- Provide operational savings, improve reliability.
- Greener future (power-related CO_2 emissions can be reduced to zero).

Cons:

- Enormous investment required for setting up photovoltaic solar panels.
- Takes several years to recover investments due to the relatively lower actual power generated.

Green Hydrogen: Hydrogen as a green energy option, can be utilized for backup power [15].Hydrogen energy systems have significant benefits, leading to extensive research on hydrogen-powered data centers [7].Green hydrogen produced from renewable energy is a clean alternative to non-renewable energy sources for powering data centers [16].Its potential for large-scale, long-term, and grid-decoupled energy storage positions it as a viable solution for backup power requirements[22]. The pivotal factor for the widespread adoption of hydrogen lies in its production cost. To facilitate progress in the field, the Hydrogen Shot was introduced as the inaugural initiative within the U.S. Department of Energy's (DOE) Energy Earthshot Initiatives. Unveiled in 2021, this Energy Earthshot is designed to expedite breakthroughs in clean energy solutions. Its primary objective is to achieve an 80 percent reduction in the cost of clean hydrogen production, aiming to reach 1 dollar per kilogram within a decade. This ambitious goal is intended to pave the way for the widespread deployment of hydrogen at a large scale [23].

Different colours of hydrogen below are used to depict the various processes involved in hydrogen production.

See below,a diagram illustrating colours of hydrogen [21].

Pros:

- Advances sustainabilty for a greener future.
- Suits quick start-and-stop needs of standby applications.
- Most common element in the universe.
- it is also the lightest and simplest element, consisting of only one proton and one electron.

Cons:

- Production of hydrogen is a complex process involving the separation of hydrogen from its molecular counterparts.
- Only five percent of the globally produced hydrogen is green hydrogen, produced by renewable energy, typically wind or solar.
- Highly flammable.
- Considered very expensive.

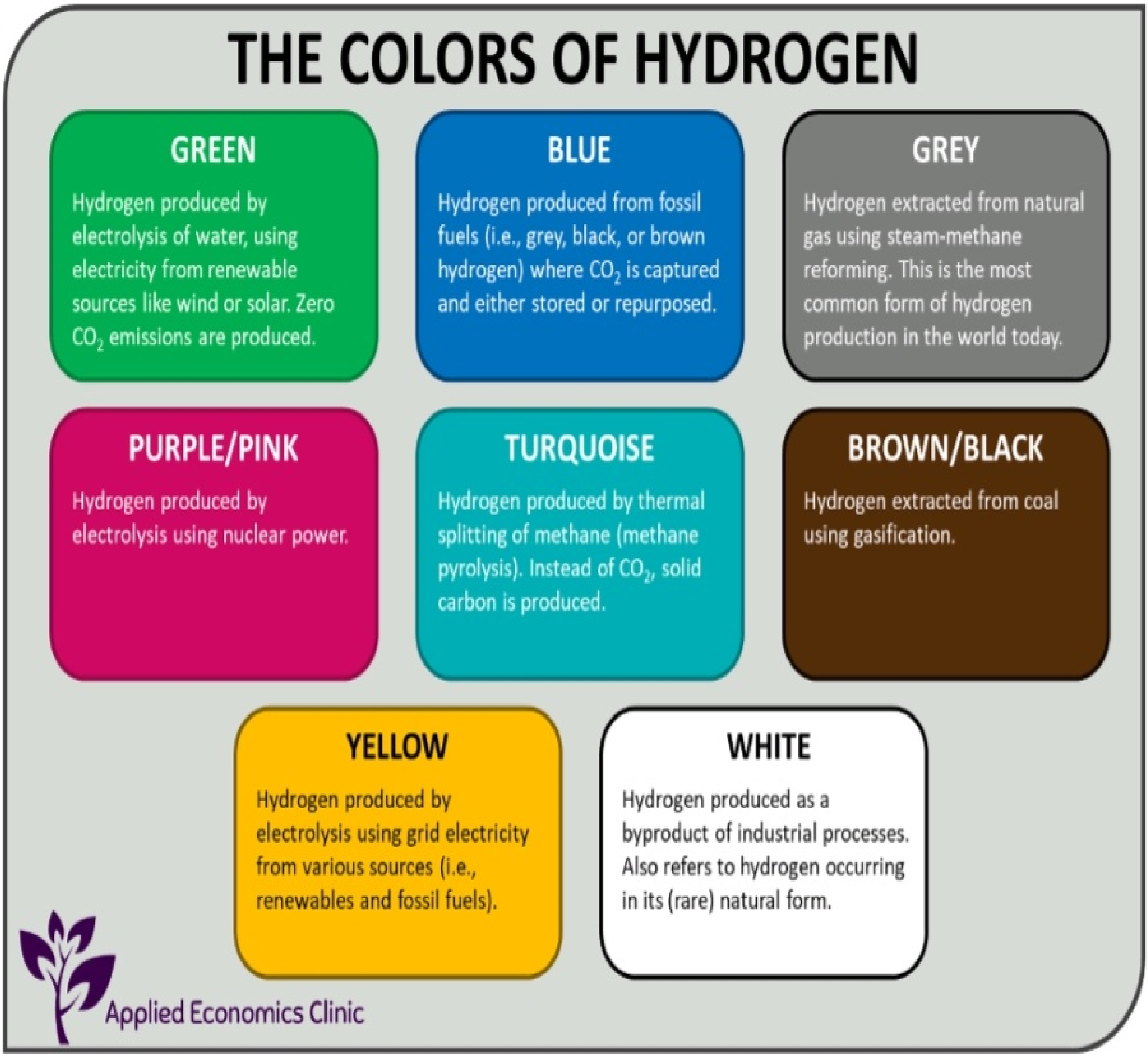

Figure 4: Colours Of Hydrogen Depicting Means Of Production

Use of Data Center Heat: Data centers generate significant heat requiring cooling systems to prevent servers from overheating. The heat produced can be used to generate power, through a process known as Combined Heat and Power(CHP). In this process, heat is used to warm up water, which is then employed to generate electricity. CHP is a highly efficient process, capturing and utilizing the heat that is a by-product of the electricity generation. This method of generating heat and power simultaneously, can reduce carbon emissions up to 30% compared to the traditional separate generation methods involving a boiler and power station [17]. In the paper "The Role of Distributed Generation and Combined Heat and Power in Data Centers" by U.S Environmental Protection Agency Combined Heat and Power Partnership, August 2007, CHP is an efficient, clean, and reliable approach to generating power and thermal energy from a single fuel source. Additionally, CHP can increase operational efficiency, reduce energy costs, and decrease emissions of greenhouse gases contributing to global climate change mitigation.
The document states "CHP systems typically achieve total system efficiencies of 60 to 80 percent, compared to only 49 percent for producing electricity and thermal energy sepa-

rately". The ability of CHP systems to generate electricity and thermal energy reduces dependence on centralized power grids and enhances the facility's resilience during grid outages. Thus, the use of CHP systems in supplying power constantly to data centers, will prevent breach in Service Level Agreements(SLAs) which outline expected performance, availability, and reliability of data center's services.

See figure below [17].

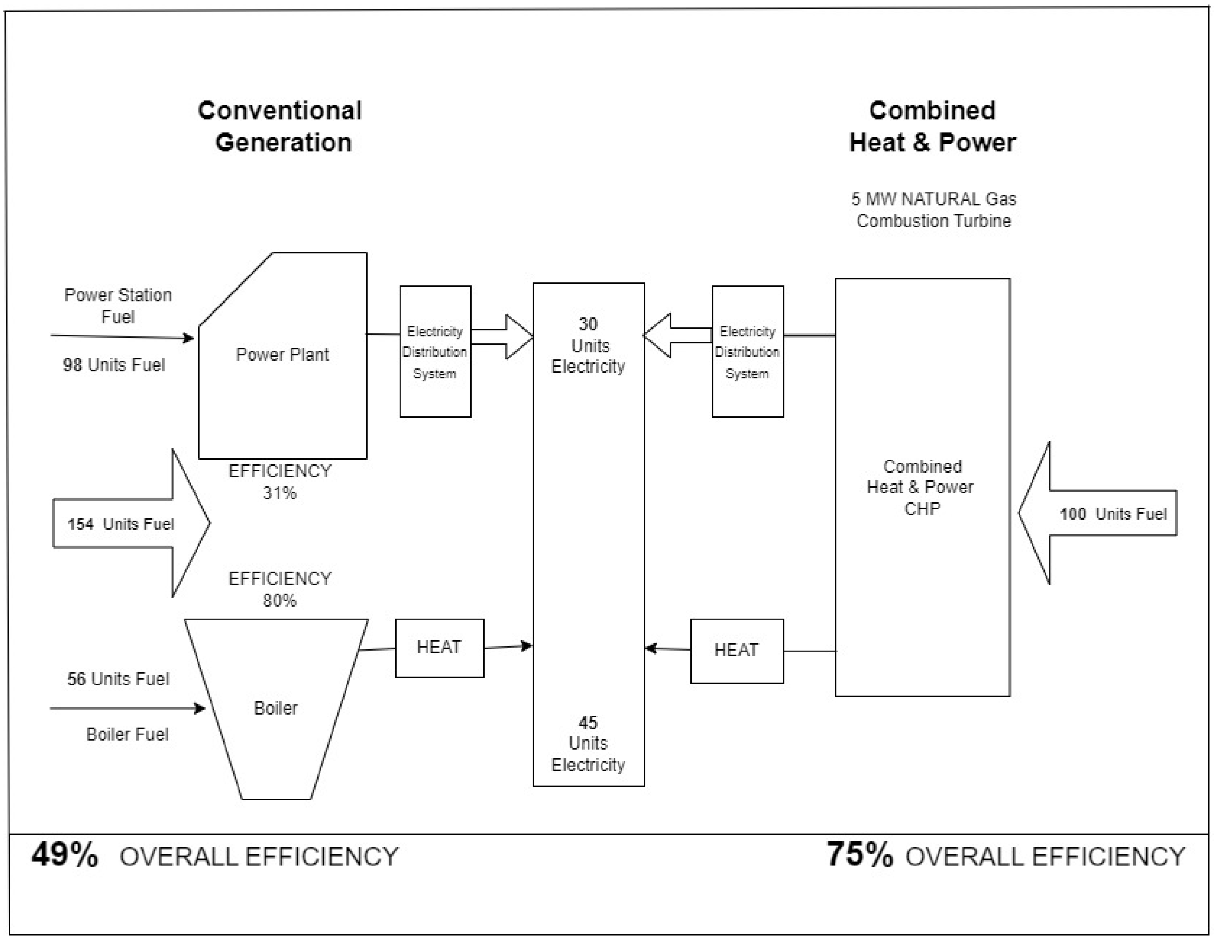

Figure 5: Combined Heat and Power Efficiency Advantage Compared To A Central Power Plant And An Onsite Boiler.

Pros:

- Reduced Energy consumption.
- Lower carbon footprint.
- Saves operational costs.

Cons:

- High initial cost for installing a CHP system.

- Maintenance costs associated with CHP systems.
- Limited scalability - finding a matching CHP system for different data centers may not be feasible due to their size.

9 Conclusion

The significance of having standby, uninterrupted backup power supply in data centers cannot be overstated. With proper planning and management, organizations can avoid financial losses resulting from power outages of data centers. Having reliable and efficient backup power system not only enhances energy efficiency but also reduces the Total Cost of Operation (TOC) for data centers.

Furthermore, prioritizing eco-friendly sustainability measures in data centers is crucial for a greener future. The goal of achieving climate-neutrality is to reach 100% renewable energy coverage in the coming years. Green data centers play a key role in maximizing energy efficiency, a critical factor for the growth and success of any company.

As the global call for eco-friendly practices in organizational operations continues, it is imperative that all relevant parties involved in managing data centers take active steps to ensure that daily operations align with the objectives and goals aimed at achieving 100% renewable energy sources for powering data centers, and given the substantial energy consumption required to keep data centers operational, especially as their number and scale increase globally, this commitment becomes even more vital.

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