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Towards a Sustainable AI Infrastructure and Ecosystem: A Review and the Road Ahead

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Abstract

The rapid advancement of artificial intelligence (AI) and generative AI (GenAI) has led to an unprecedented rise in energy consumption by data centers. Global electricity demand for AI-driven infrastructure is projected to surge by 160% within the next two years, raising concerns about energy availability and sustainability. This study explores alternative energy sources—including hydrogen, nuclear, and geothermal power—to mitigate the AI energy crisis. Using a mixed-methods approach, the research analyzes energy trends, industry innovations, and policy frameworks. Key findings suggest that small modular reactors (SMRs) and hydrogen-powered data centers present viable, long-term solutions. In addition to offering industry executives useful advice and suggestions for legislative actions to encourage the use of clean energy, the report highlights the crucial role that regulations play in enabling a seamless transition to sustainable energy sources. By supporting sustainable energy solutions for AI infrastructure, this study supports SDGs 7 (Affordable and Clean Energy), 9 (Industry, Innovation, and Infrastructure), 11 (Sustainable Cities and Communities), and 13 (Climate Action).

Keywords: *AI energy consumption, sustainable data centers, hydrogen power (SDG 7), small modular reactors (SMRs) (SDG 9), climate-friendly infrastructure (SDG 13).*

I. INTRODUCTION

The rapid expansion of AI technologies has significantly increased energy consumption in data centers, with electricity demand projected to rise by 160% within two years. Traditional power sources struggle to keep pace, underscoring the urgency for sustainable energy solutions. This paper explores how AI-driven data centers can address rising energy demands while prioritizing sustainability, examining innovative alternatives such as hydrogen and nuclear energy. AI technologies can help reduce energy consumption of other business however AI computing itself can be taxing in terms of energy consumption.

AI and GenAI technologies demand significantly more power than traditional computing systems. Estimates suggest that by 2026, electricity consumption from AI data centers could increase more than tenfold, potentially doubling global data center energy usage by 2030. In the U.S., AI-related power consumption is projected to triple by the end of the decade, raising concerns about grid capacity and sustainability.

To support this expansion, tech companies are investing heavily, with projected spending of $1 trillion over the next four years on AI infrastructure. AI data centers consume several giga watts of power, significantly more than conventional data centers, exacerbating energy shortages and sustainability challenges.

Despite AI's growing importance in society, nothing is understood about how it will affect the environment. Society is quickly becoming dependent on AI despite its high energy usage without fully comprehending the implications. There are initiatives to lessen its impact, but they ought to come first before broad adoption. Since energy use is a major problem in the climate crisis, the claim that AI primarily uses green energy is insufficient. Given that many AI applications could not be worth the long-term effects, ethical AI development

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must begin by determining if the environmental costs are justified

SDG7 works on providing access to modern, clean and sustainable energy with the nodal agency being International Energy Agency. SDG 9 looks at innovation and infrastructure for a sustainable future. SDG 13 is an actionable goal for tackling climate change. Artificial Intelligence is a driver for all the above mentioned SDGs however it is also a cause of concern that energy consumption of AI Models and AI tools is much higher and is expected to increase in multifolds in usage and consumption. Hence it becomes essential to study the energy consumption of AI and its implications towards a sustainable future.

II. RESEARCH OBJECTIVES

This study aims to evaluate and assess alternative clean energy solutions for AI-driven data centers. The central research questions are:

1. To analyse energy consumption patterns of AI ecosystems and its overall impact on energy consumption.
2. To study how data centers and policymakers are working to reduce AI led energy consumption and ensure the sustainability of AI operations.

By analyzing emerging energy technologies, industry investments, and regulatory policies, this study seeks to provide actionable insights for industry leaders and policymakers.

III. LITERATURE REVIEW

Existing research highlights the increasing electricity demand of AI systems and the limitations of current grid infrastructure. Several studies suggest that hydrogen and SMRs (small modular nuclear reactors) could provide stable, low-carbon energy solutions. However, challenges remain in terms of cost, scalability, and regulatory approvals.

Microsoft has revealed that its CO2 emissions have increased by about 30% since 2020 as a result of data center construction. Microsoft has invested in ChatGPT developer OpenAI and has placed generative AI capabilities at the core of its product offering. The energy demand associated with data centers was a major factor in Google's over 50% increase in GHG emissions in 2023 compared to 2019.

Artificial intelligence is an electricity hog. Google says its total greenhouse gas emissions climbed nearly 50% over five years, mostly due to electricity that powers AI data centers.

A. Challenges and gaps

i. There is a lack of established sustainability metrics for AI models.
ii. AI's trade-off between performance and energy usage raises ethical questions.
iii. The environmental impact of AI is not adequately regulated by policy frameworks.

B. Key insights from prior research

i. AI-driven data centers will consume over 500 terawatt-hours (TWh) by 2027.

ii. Hydrogen energy is emerging as a zero-emission alternative, with initiatives like ECL's hydrogen-powered data centers demonstrating feasibility.

iv. Nuclear energy, particularly SMRs, is being explored by companies like Microsoft to ensure a reliable, continuous power supply.
v. Geothermal energy is gaining traction, with firms like Fervo Energy investing in deep-drilling methods.

Despite investments in renewables, achieving carbon-free AI infrastructure remains challenging due to high costs and regulatory hurdles

IV. RESEARCH METHODOLOGY

A mixed-methods approach was employed, including:

- Quantitative Analysis: Examination of AI energy consumption trends using data from the International Energy Agency (IEA) and industry reports.
- Qualitative Case Studies: Analysis of major tech companies investing in hydrogen, nuclear, and geothermal energy for data centers.

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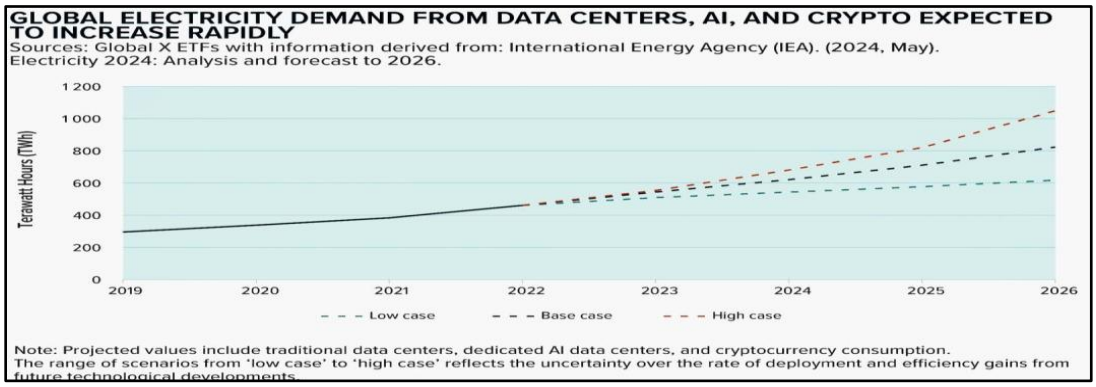
- Policy Review: Examination of regulatory frameworks supporting clean energy adoption in AI-driven infrastructure.

V. DISCUSSION

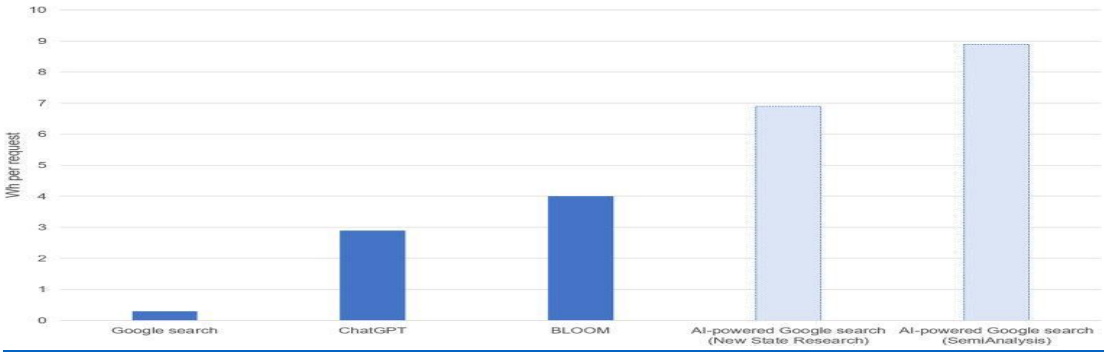
A. Growing energy demand for AI, data centres and crypto

AI's demand in future electricity needs is relatively smaller however the requirement for AI data centers is increasing manifold. Also these data centres are concentrated in smaller localities. Case in point can be the county of Virginia in USA which has seen an unprecedented increase in the construction of large scale AI data centres which will support technology firms in generative AI technology. Virginia has more than 500 data centre facilities. In Ireland data centres account for 20% of the country's electricity consumption and are mostly concentrated near Dublin. Companies usually build data centres close to each other so that they can share power grids and cooling systems and hence their concentration is dense. In India the average consumption of data centres meant for AI applications consumes 100 to 200 kwh per rack. To have a fair idea about the magnitude of this consumption an average Indian urban household consumes approximately 5 to 6 kwh of power.



Source: Electricity 2024, Analysis and forecast to 2026

A typical Google search requires 0.3 wh of electricity , whereas OpenAI's ChatGPT requires 2.9wh electricity per request. On and average there are 9 billion searches daily , which would mean that there will be requirement of 10 TWh additional electricity. NVIDIA the leader in making AI servers has shipped 1,00,000 units in the year 2023 which will consume 7.3 Twh of electricity and it is expected to grow ten fold in the next three to four years.



Source: Alex de Vries (2024). The growing energy footprint of artificial intelligence

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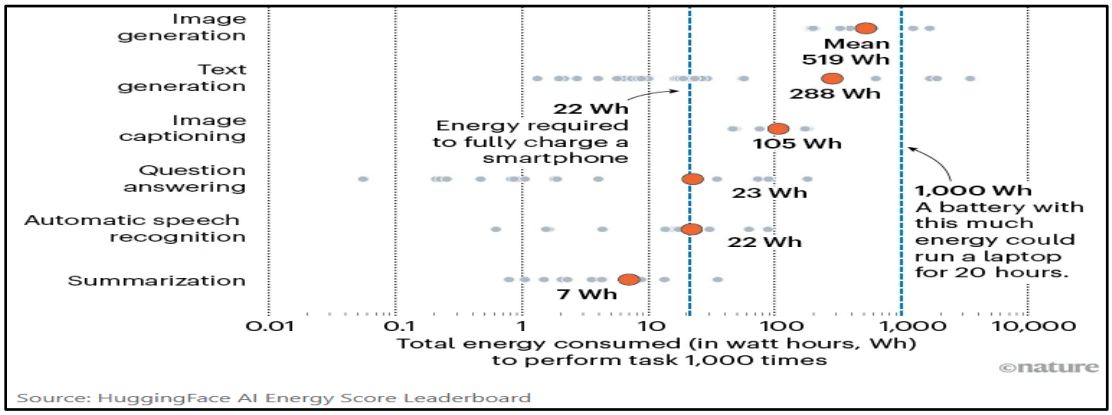
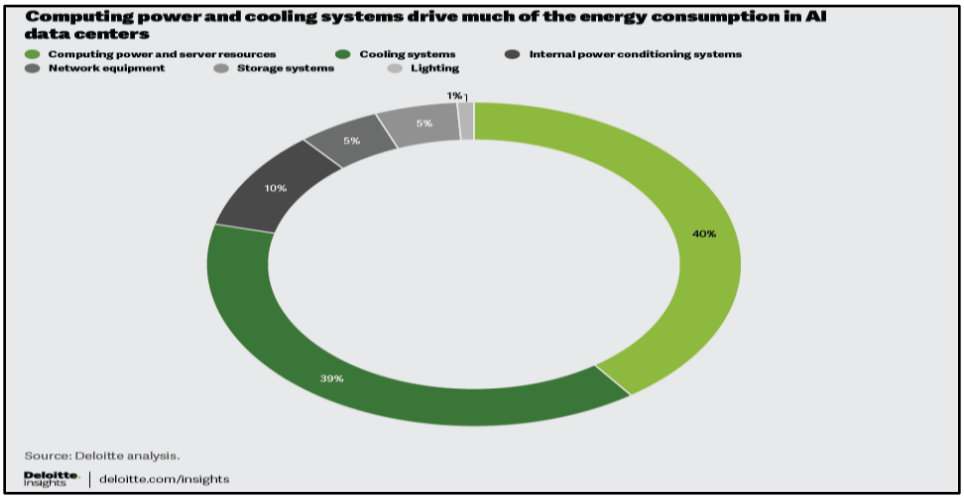


Energy consumption from different AI tools differ in magnitude with the highest energy consumption for image generation and the lowest for speech recognition and summarization. The requirement is much higher and comparable to charging a laptop or a smartphone.

Meeting AI's growing energy needs presents several challenges:

- Grid limitations: AI hubs like Virginia, Ireland, and China are facing power shortages, necessitating grid expansion investments.
- Reliability concerns: AI data centers require continuous power, making the shift to renewables difficult due to intermittency issues.
- Dependence on fossil fuels: Some companies are turning to natural gas as a temporary solution, potentially slowing down decarbonization.



Computing Power & Cooling Energy Consumption in AI Data Centers

B. Renewable Energy Solutions for AI

As AI's energy demands continue to grow, tech companies are prioritizing renewable energy investments:

- Microsoft aims for 100% zero-carbon energy by 2030.
- Google is committed to 24/7 carbon-free energy.
- Meta has pledged to achieve net-zero emissions by the end of the decade.

Beyond solar and wind, companies are expanding their

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energy mix by incorporating:

- Battery storage systems to improve energy reliability.
- Hydroelectric power to provide stable, long-term energy.
- Geothermal energy as a viable baseload power solution.

This diversified approach is essential to ensuring uninterrupted and sustainable AI operations.

There are however challenges in solar energy and renewable energy as fluctuating demand and supply would not match. Reliability of solar panels remains a concern for countries due to weather related conditions. Issues around storage and sourcing of solar still remains a problem and is expensive and in its nascent stages.

C. Emerging Technologies for AI Energy

To address these challenges, next-generation energy solutions are being explored:

I. Small Modular Reactors (SMRs)

- Provide scalable, zero-carbon energy for AI data centers.
- Microsoft and TerraPower are leading efforts to integrate SMRs into AI infrastructure.

II. Hydrogen-Powered AI Data Centers

- Hydrogen fuel cells offer a clean, flexible energy source.
- Companies like ECL are developing hydrogen-based AI data centers with zero carbon emissions.

III. Quantum Computing & Fusion Energy

- Quantum computing could drastically reduce AI energy consumption in the future.
- Fusion energy has the potential to provide unlimited clean power, but commercialization remains several decades away.

IV. Advancements in Cooling & Waste Heat Recovery

- Liquid cooling (direct-to-chip & immersion cooling) significantly improves efficiency for AI workloads by reducing energy waste and thermal inefficiencies.
- Waste heat from AI data centers is being repurposed for district heating, industrial applications, and agricultural use, contributing to a more circular energy economy

D. Corporate Efforts in Renewable Energy Adoption

Amazon, Meta, and Google are at the forefront of renewable energy procurement, addressing the growing power demands of AI-driven operations. As seen in Image 1, Amazon leads with 5,629 MW of solar and 3,135 MW of wind energy, while Meta prioritizes solar (3,052 MW). Google, though procuring 996 MW, continues expanding its clean energy efforts.

The balance between solar and wind is key to corporate sustainability. Solar is favored for its scalability and cost-effectiveness, while wind, though efficient, depends on location and infrastructure. As AI models and data centers consume increasing power, these companies set crucial sustainability benchmarks, ensuring a greener future for the industry.

E. Regulatory and Policy Considerations

AI is increasingly being used to optimize data center operations, reducing energy consumption through predictive workload management, real-time cooling adjustments, and proactive equipment maintenance. Edge computing is also emerging as a solution to distribute AI workloads efficiently, reducing reliance on centralized data centers and integrating localized renewable energy sources.

Governments and regulatory bodies are addressing AI-driven energy demand through efficiency standards, grid stability measures, carbon pricing, and financial incentives. Policies are encouraging sustainable data center designs and renewable energy co-location. Additionally, international collaboration is fostering innovation, knowledge sharing, and cross-border clean energy procurement, ensuring AI's growth aligns with

sustainability goals.

The European Parliament is among the regulators putting laws into place to monitor and control AI's energy usage. There are growing demands for AI systems to record their energy use in order to maintain accountability and transparency. To lessen AI's carbon footprint, governments and legislators are also promoting research into innovative chip technology and effective cooling techniques. Finding a balance between AI's effects on the economy and the environment is still a top goal, and policies should encourage both sustainability and innovation.

VI. CONCLUSION

The use of AI is not slowing down; on the contrary, its incorporation into business and governmental processes will only quicken. Sustainable infrastructure must be given first priority as Asia-Pacific countries continue their digital transformation journeys to guarantee that environmental stability is not sacrificed for AI innovation.

This study highlights the urgent need for sustainable energy solutions to address the rising energy consumption of AI-driven data centers. Key takeaways include:

- Hydrogen and SMRs offer promising long-term alternatives, but require policy support and infrastructure investment.
- Renewable energy integration is critical, but grid reliability and storage solutions must improve.

Future research should focus on optimizing energy storage technologies and enhancing regulatory frameworks to support clean energy adoption in AI.

The findings provide valuable insights for policymakers and industry leaders, guiding future AI energy investments and sustainable infrastructure development.

The findings provide valuable insights for policymakers and industry leaders, guiding future AI energy investments and sustainable infrastructure development.

First, practical regulations and industry standards are required. Lack of data and proper documentation procedures during AI development and deployment are major barriers to making AI more sustainable.

Second, we point out conceptual implications, including the necessity for investigation and contemplation of the interdependencies and entanglements between the systemic risks and the sustainability consequences of AI systems.

The offered list of criteria can be used as a base for additional study.

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