Bulletin of Nexus
Multidisciplinary International Research Journal, Double-Blind Peer Reviewed, Open Access Journal
ISSN : 3065-7865 / Volume-2, Issue-4 / April - 2025

Original Article

Impact of Data Centre on Climate Change: A Review of Energy Efficient Strategies

Shruti Sachin Ghorpade
Student, Department of Computer Science, Hirwal Education Trust's College of Science (Computer Science & Information Technology), Mahad-Raigad

Manuscript ID:
BN-2025-0204012

ISSN: 3065-7865

Volume 2

Issue 4

April 2025

Pp. 70-73

Submitted: 31 Jan 2025

Revised: 06 Feb 2025

Accepted: 11 Mar 2025

Published: 30 Apr 2025

DOI:
10.5281/zenodo.17077693
DOI link:
https://doi.org/10.5281/zenodo.17077693

Abstract:

Data centres are the foundation of the digital economy, supporting the growth of cloud computing, online services and very big data processing. Like many sectors, data centres are experiencing rapid growth, which increases many risks around energy use and climate. After providing a description of the current operations of data centres and links to climate change; energy use, carbon emissions and heat generation this review continues to highlight areas of energy inefficiency and provides a discussion of newer techniques in energy efficiency including virtualization, liquid cooling, renewable energy integration, artificial intelligence and resource optimization and server consolidation. By analysing the case studies and current state-of-the-art practices included in this review we are able to ascertain the likelihood of environmentally sustainable design and operational models to reduce carbon emissions profile.

Keywords: *Data Centres, Climate Change, Energy Efficiency, Carbon Emissions, Sustainable Computing, Green IT, Renewable Energy, Virtualization, Cooling Technologies, AI Optimization*

Introduction:

The rapid growth of digital technologies and cloud services in the past ten years has prompted an insatiable demand for storage, processing, and transmission of data. Data centres are essential to this digital transformation. A data centre is a large, centralized facility that contains servers, storage devices (e.g. hard drives, storage arrays, and storage clusters), and networking equipment (e.g. switches and routers). Today, data centres play an essential role in all aspects of computing and communications. Moreover, data centres are also some of the largest consumers of power globally, responsible for significant amounts of carbon emissions.

Data centres currently consume an estimated 1–2% of the world's total electricity. This number is likely to increase with the rapid uptake of artificial intelligence (AI), Internet of Things (IoT), and 5G technologies. Importantly, data centres' contribution to costly and harmful carbon emissions, combined with their reliance on non-renewable energy sources and inefficient cooling practices, means that a data centre's environmental impact can be quite significant. Climate change is an urgent global issue, and the sustainability of data centre infrastructure has become an important area of focus for researchers, practitioners, and policy makers.

This paper collects evidence regarding the environmental impacts of data centres in relation to climate change, as well as frameworks that have been developed to improve the energy efficiency of data centres.

Address for correspondence:
Shruti Sachin Ghorpade,Student, Department of Computer Science, Hirwal Education Trust's College of Science (Computer Science & Information Technology), Mahad-Raigad
Email: - shrutighorpade007 @gmail.com

How to cite this article:
Ghorpade, S. S. (2025). Impact of Data Centre on Climate Change: A Review of Energy Efficient Strategies. Bulletin of Nexus, 2(4), 70–73. https://doi.org/10.5281/zenodo.17077693

Quick Response Code:

Website: https://bnir.us

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Specifically, the potential for, and implications of advancements in technology such as virtualization, advanced cooling practices, integration of renewable energy, and energy optimization via AI will be discussed, including evidence of best practice.

Literature review:

The rise of digital services has led to significant growth of data centre usage, putting pressure on energy consumption and creating concerns about their environmental impacts. Numerous paper have researched the link between data centre operation, energy consumption, and the impacts on climate change; some paper have also researched energy efficient strategies in order to lower their carbon footprint.

Energy Consumption Trends:

Data centres consume a sizable proportion of global electricity, and some estimate they consumed 1–2% of total global electricity use. Reports and studies, including the International Energy Agency (IEA), highlight that demands for cloud-computing, video streaming, and artificial intelligence are signalling growing energy needs. The desire for an improved hardware performance, alongside expectations for workloads to be optimized have meant that the scale of data centre operations grows into the current timeline without reducing demands on energy resources.

Environmental Impact:

Research from multiple scholars about the carbon impact of data centre sustainability largely focuses on how the energy that powers their operation primarily comes from harmful fossil fuels. Massenet et al. (2020) observed through its research that greenhouse gas emissions remain serious issues as documented energy efficiency has become better looking towards the future when energy demands are rising as it relates to data. What is mutually understood in the literature is that there is a significant environmental impact of cooling, and e-waste is part of the environmental footprint is leave in data centres.

Energy Efficiency Solutions

As we work to lessen the environmental impact of IT and data centres, we have begun to innovate and share best practices as follows:

- Virtualization and Server Optimization: Virtualization lessens hardware dependency and is architecture to enable multiple workloads to run simultaneously on one server and reduce idle energy consumption.
- Advanced Cooling Technologies: Research advocates developing alternatives to traditional cooling which include replacing old air-based cooling techniques, liquid cooling, free air cooling, or immersion cooling solutions as models that are improving efficiency and have lower environmental footprints.
- Renewables: Research has found that, as firms and social organizations continue to adopt wind, solar and hydropower, some major cloud and IaaS providers such as Google and Microsoft have joined the ranks of companies investing in 100% data centres powered by renewables. From research, this addition has drastically reduced operational emissions.

AI for Energy Efficiency: Machine learning algorithms are emerging for enhancing the mixed real time management of energy use on cooling from better data of how much energy is required utilizing state-of-the-art data centre cooling methods. This helps improve efficiency and reduce unnecessary action or actions from wasting energy and money.

Research Methodology

This research takes a qualitative / systematic literature review (SLR) approach to study the impact of data centres on the environment, and to review the energy-efficient strategies that energy-efficient adaptations tried to address climate change mitigation.

Research Method

The intention of this study was to identify, interpret and collate existing peer-reviewed articles, technical reports, and policy documents published between 2010 to 2024 in order to recognize good practices, technological change, and trends toward data center sustainability.

Data Collection

The literature was taken from credible academic databases namely:

- IEEE Xplore
- ScienceDirect
- SpringerLink
- Google Scholar

The following keywords were used during the search: “data centre energy consumption,” “climate change,” “green data centres,” "energy efficiency," "renewable energy in IT," "data centre cooling," “AI in energy optimization."

Inclusion criteria were:

- Publications between 2010–2024
- Peer-reviewed journals, conference proceedings, and white papers
- Studies that focussed on energy consumption, carbon emissions, and energy-saving strategies, of data centres

Exclusion criteria were:

- Non-English papers

- Papers not related to the infrastructure, or environmental effects of data centres.

Data analysis

A thematic analysis approach was adopted to classify the findings into thematic categories: Sources and patterns of energy use Technological solutions (e.g., virtualization, cooling systems, integrating renewables) Policy and regulatory frameworks Environmental outcomes (e.g., emissions reduction, efficiency indicators). The literature was reviewed for what contributions to understanding both the problem (impact on the environment) and the solutions strategies (energy efficiency). Themes were generated and synthesized to give a full picture of what we currently know or do not know.

Limitations

While this study attempts to present a wide range of strategies and technologies, there are limitations in the available open access publications and the bias (in some cases) in published studies. Also, quantitative assessments or simulations are outside of the scope of this literature review.

Case Study

1. **Google's AI-based cooling system**
   To optimize cooling, Google and DeepMind implemented an AI-based control system in Google Data Centres that status was stored for future reference. The AI-based control system used machine learning algorithms to predict future temperatures and cooling loads; with this information, the system could automatically select a cooling control option leading to 40% reduction in cooling energy. This is a great example of the possibilities of AI and uses in energy management in real-time.
2. **Facebook's Lulea Data Centre (Sweden)**
   Facebook's Data Centre Lulea sits in the Arctic Circle and utilizes free-air cooling. The facility's energy source is 100% renewable hydroelectric energy. The facility is 1 of the 2 most efficient data centres on the planet with a Power Usage Effectiveness (PUE) ratio of 1.07.
3. **Microsoft's Project Natick**
   Microsoft's Project Natick explored the idea of underwater data centres. The project submerged a routinely dry sealed container of Windows servers in the ocean. The ocean's cold water represented a natural cooling source, allowing Microsoft to reduce and eliminate mechanical cooling systems altogether. The tests showed that the submerged container showed fewer failures and energy generation compared to similar locations. The tested approach offers new opportunities in sustainable data centre design so that computers do use more energy and create a negative environmental footprint.

Conclusion

Data centres are vital to the digital economy, but they are causing trouble globally on climate targets due to their increasing energy usage. As the review above has illustrated, data centres are substantial energy users and sizable contributors to greenhouse gas emissions (GHGs), especially as an electricity load from fossil fuels. However, it seems a plethora of new innovations and technologies are emerging to solve these challenges—from AI driven optimization and virtualization to advance cooling technologies and renewable energy integration.
Moreover, piloting case studies such as Google's AI cooling and Microsoft's underwater data centres indicate sustainable data infrastructure is manageable and benefits larger cost and environmental plans. We are also witnessing useful and legitimate policy development and industry standards regarding the development of greener and more efficient data centres.

Nonetheless, scalability, risk of standardization, environmental burden of devices and disposal remain challenges. As advocates, we believe more research, policy development, and industry alignment through cooperation will help ensure that the future of data centres is not only powerful but also planet positive.
In short, the data center transition for sustainable computing is not just a tech change, it is a necessary reflection to address climate change and make sense of a greener future for the digital economy.

Acknowledgment
I am Miss. Shruti Sachin Ghorpade thankful to HOD Ms.Komal Gaikwad, Department of Computer Science, Hirwal Education Trust College of Science (Computer Science & Information Technology) for granting permission to carry out the work.

Financial support and sponsorship
Nil.

Conflicts of interest
I am Miss. Shruti Sachin Ghorpade (author) declare that there are no conflicts of interest regarding the publication of this paper

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