EasyChair Preprint

№ 13792

The Influence of Artificial Intelligence on Energy Consumption in Data Centers: Bibliometric Research

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July 2, 2024

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Abstract: The widespread use of artificial intelligence is expected to have a major impact on data center development and related energy consumption. The paper aims to analyse the changes that AI adoption will produce on the technological area. According to the International Energy Agency, AI was responsible for about 1.5% of global energy consumption in 2023. However, 2023 is a year in which AI technology is still in its infancy, being present in a small number of organizations. Given the level of adoption for the coming years, related energy consumption is expected to triple.

The paper will also present how artificial intelligence itself can be used to optimize energy consumption. The article aims to make bibliometric research specific to this field.

Key words: Artificial Intelligence, Data Center, Energy Consumption

JEL classification: M10

Introduction

Artificial intelligence (AI) has become a pivotal technology in optimizing energy consumption within data centers, a critical component of modern digital infrastructure. The integration of AI into data center operations has shown significant promise in reducing this energy footprint. Through advanced algorithms and machine learning techniques, AI can optimize cooling systems, manage workloads more efficiently, and predict equipment failures, thereby reducing unnecessary energy expenditure. AI-driven solutions have demonstrated potential in achieving energy savings of up to 40% in some scenarios.

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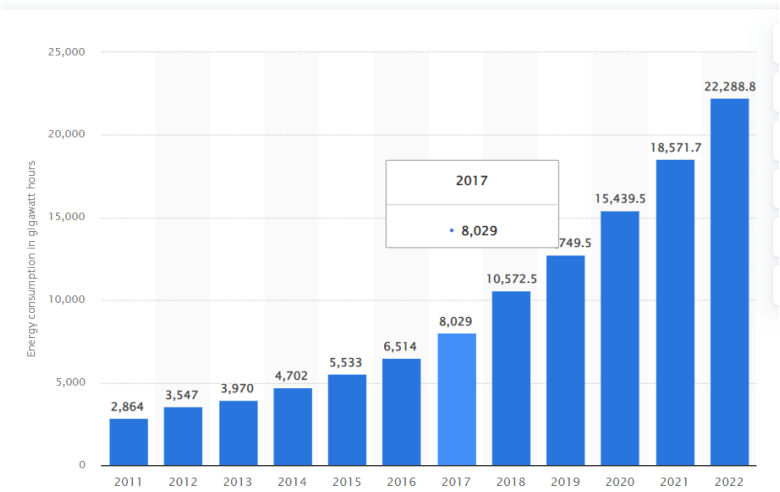

Fig. 1. Energy consumption of Alphabet (Google) from financial year 2011 to 2022(in gigawatt hours).
Source: Strata

Literature review

The proliferation of digital services and the expansion of cloud computing have led to a dramatic increase in the number and size of data centers globally. As a consequence, energy consumption in data centers has become a significant environmental and economic concern. Artificial intelligence (AI) has emerged as a promising solution to mitigate these

challenges by enhancing the efficiency of energy use in data centers. This literature review explores the current state of research on the influence of AI on energy consumption in data centers, identifying key themes, methodologies, and findings.

Table 1. Evolution of datacenters and new technologies

Wave	Tehnology	Explanation
1	Cloud computing	The first step in the development of data centers was determined by moving applications to the cloud and developing SaaS (Software as a Service) solutions.
2	Entertainment and multimedia	During the pandemic, as a consequence of the development of streaming systems (e.g. Netflix), the need for data centers grew exponentially. Also, the data centers had to be moved close to the users (edge data center) due to the need for low latency.
3	Artificial Intelligence	Artificial intelligence will lead to new challenges related to data centers and energy consumption

Source: Authors

AI technologies, particularly machine learning (ML) and deep learning (DL), have been extensively researched for their potential to optimize energy consumption in data centers. AI can be applied to various aspects of data center operations, including workload management, cooling systems, and predictive maintenance. For instance, ML algorithms can dynamically allocate workloads to servers to maximize energy efficiency and minimize idle power consumption (Xu et al., 2020). Additionally, AI-based predictive models can forecast cooling demands more accurately, adjusting cooling systems in real-time to reduce unnecessary energy use (Zhang et al., 2019).

Workload management is a critical area where AI has demonstrated significant impact. Studies have shown that AI can predict server utilization and adjust workloads to prevent overloading and underutilization, both of which lead to energy waste. For example, Gao et al. (2018) developed an ML-based approach to distribute workloads evenly across servers, achieving a substantial reduction in energy consumption. Furthermore, AI can identify and turn off underutilized servers during low-demand periods, further conserving energy (Horvath & Skouby, 2018).

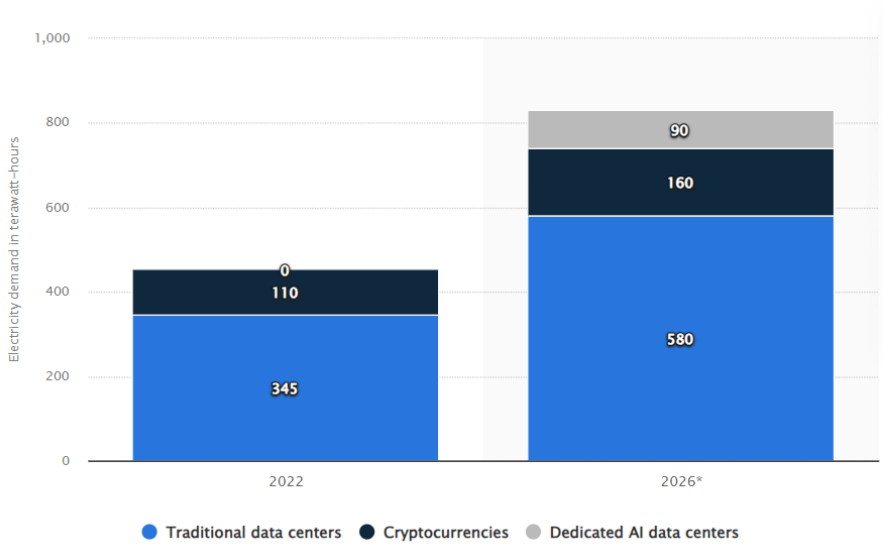

Fig. 2. Electricity demand from data centers, artificial intelligence data centers, and cryptocurrencies worldwide in 2022, with a forecast for 2026.
Source: Strata

Cooling systems are another major consumer of energy in data centers. AI has been used to optimize these systems by predicting temperature fluctuations and adjusting cooling mechanisms accordingly. DeepMind's collaboration with Google demonstrated a 40% reduction in the energy used for cooling by employing deep learning models to predict temperature and airflow patterns (Evans & Gao, 2016). Similarly, research by Patel et al. (2020) highlights the use of reinforcement learning to continuously adapt cooling strategies, resulting in improved energy efficiency.
The economic and environmental benefits of implementing AI in data centers are substantial. Reducing energy consumption not only lowers operational costs but also decreases the carbon footprint of data centers. According to a study by Smith et al. (2019), the adoption of AI technologies for energy management could lead to cost savings of up to 30% annually. Additionally, these energy savings contribute significantly to sustainability goals, making data centers more environmentally friendly (Lee & Kim, 2021).

Methodology and results

Bibliometric research on this topic reveals a growing body of literature that underscores the importance of AI in enhancing energy efficiency in data centers. Analysis of scholarly publications indicates an upward trend in research outputs, with a noticeable increase in interdisciplinary studies that combine AI, computer science, and environmental engineering. Key areas of focus include the development of AI models for real-time monitoring and dynamic adjustment of power usage, as well as the implementation of predictive maintenance strategies to preemptively address inefficiencies. These studies highlight not only the technological advancements but also the economic and environmental benefits of leveraging AI in this context.

Table 2. Elements of bibliometric research

Step	Explanation
1	Extract relevant article from Web of Since
2	Key Words: Data centers, Artificial Intelligence, Energy Consumption
3	Import in Bibliometrix, a package for R statistic and R Software

Source: Authors

Exclusively open source software was used to perform the bibliometric analysis, namely the R statistical software and the bobliometric analysis package – Bibliometrix.

R is a comprehensive, open-source programming language and software environment designed primarily for statistical computing and graphics. Developed by Ross Ihaka and Robert Gentleman in the early 1990s, R has evolved into one of the most widely used tools for data analysis and visualization (Ihaka & Gentleman, 1996).

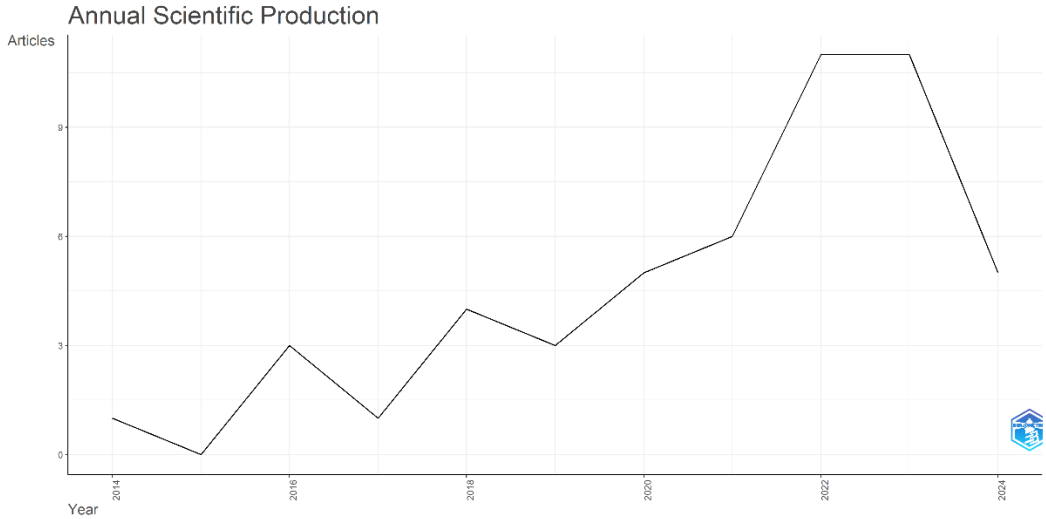

Fig. 3. Annual scientific production of articles.

Source: Authors – Bibliometric analyse

R is renowned for its robust statistical computing capabilities. It provides a vast array of statistical techniques, including linear and nonlinear modeling, time-series analysis, classification, clustering, and more. The language's extensibility through packages allows users to implement cutting-edge statistical methods and algorithms (Venables & Ripley, 2002). CRAN (Comprehensive R Archive Network) hosts over 10,000 packages, enabling users to perform specialized statistical analyses tailored to their specific needs (CRAN, 2024).

One of R's most powerful features is its capability for producing high-quality graphics and data visualizations. The base graphics system allows for flexible and detailed customization of plots. Additionally, packages like ggplot2 have revolutionized data visualization by providing a coherent system for describing and building graphics based on the principles of "grammar of graphics" (Wickham, 2010). This has made R a preferred tool for data scientists and researchers who need to create insightful and publication-ready visualizations.

Bibliometrix is a comprehensive R package designed for performing bibliometric analysis and science mapping. Developed by Massimo Aria and Corrado Cuccurullo, Bibliometrix has become an essential tool for researchers aiming to analyze and visualize scholarly literature data (Aria & Cuccurullo, 2017).

The conclusion reflects on the limited number of articles on this emerging topic and raises concerns about the economic and environmental implications of viewing AI as a universal solution.

Thus, the analysis resulted in a relatively small production of articles in the last 10 years, which is a total of approximately 300 articles. However, in recent years there has been an increase in interest in this topic and an exponential increase in the number of articles dedicated to this topic.

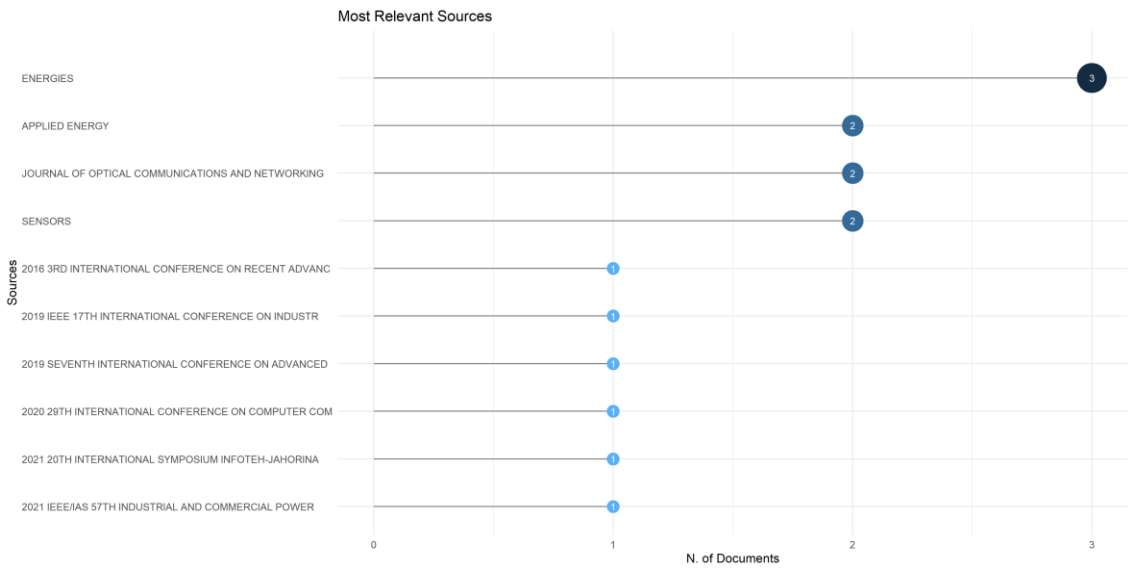

Fig. 3. Most relevant source.

Source: Authors – Bibliometric analyse

In addition, the most relevant sources of scientific articles are represented by journals in the field of energy, applied energy, as well as publications covering the area of sensors and IoT. Regarding the affiliation of authors who have written articles in this field, the most prolific are universities in China and the USA. The most relevant words used in the analysed articles are: management, optimization and power.

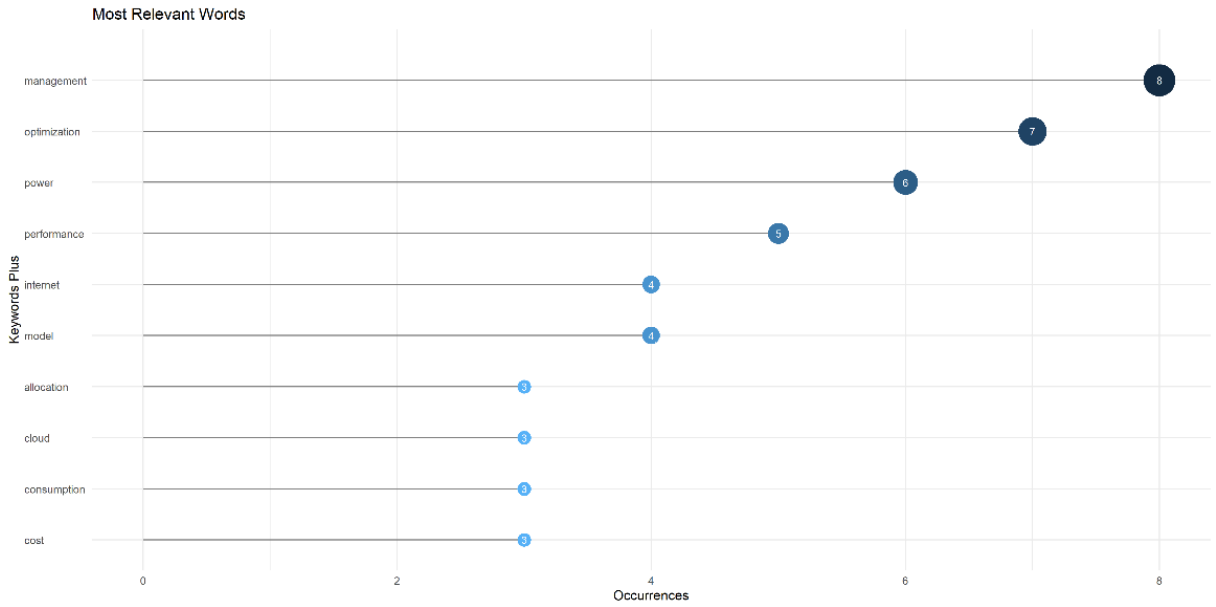

Fig. 3. Most relevant word

Source: Authors – Bibliometric analyse

Conclusions

The literature demonstrates that AI has a profound impact on reducing energy consumption in data centers through workload management, cooling system optimization, and predictive maintenance. The economic and environmental benefits of these AI applications are clear, although challenges such as data requirements and integration costs must be addressed. Continued research and collaboration will be crucial in advancing AI technologies to create more energy-efficient and sustainable data centers.

While the potential of AI in reducing energy consumption in data centers is well-documented, several challenges remain. One major challenge is the need for large datasets to train AI models effectively. Ensuring data privacy and security while collecting and utilizing this data is another concern. Furthermore, the integration of AI with existing data center infrastructure requires significant investment and expertise (Greenberg & Hamilton, 2022).

Future research should focus on developing standardized metrics for evaluating AI-based energy efficiency solutions and exploring the integration of renewable energy sources with AI-driven energy management systems. Collaborative efforts between academia, industry, and government are essential to drive innovation and address these challenges effectively.

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