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ENERGY CONSUMPTION OF DATA CENTERS AND THE PRIMARY ENERGY METRIC: GLOBAL ANALYSIS 2000–2024 AND PROJECTIONS UNTIL 2030

CONSUMO ENERGÉTICO DOS DATA CENTERS E A MÉTRICA DA ENERGIA PRIMÁRIA: ANÁLISE GLOBAL 2000–2024 E PROJEÇÕES ATÉ 2030

CONSUMO ENERGÉTICO DE LOS CENTROS DE DATOS Y LA MÉTRICA DE ENERGÍA PRIMARIA: ANÁLISIS GLOBAL 2000–2024 Y PROYECCIONES HASTA 2030

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ABSTRACT
The digitalization of the 21st century, driven by cloud computing, big data, and generative artificial intelligence, has transformed economic, scientific, and social systems. Data centers have become critical infrastructure for information processing and storage, yet their energy impact is often underestimated, as traditional studies focus only on electricity consumption, ignoring the primary energy required from extraction to distribution. This study analyzes the global energy consumption of data centers between 2000 and 2024, using primary energy as the metric, and focuses on ten strategic countries responsible for over 70% of global consumption. It calculates the percentage share of data centers, identifies critical growth milestones, compares their consumption with the global energy surplus, analyzes regional disparities, and projects scenarios until 2030. Although accounting for only about 0.4% of global primary energy, data centers are growing rapidly and are geoFigureically concentrated in the United States, China, and the United Kingdom, generating energy inequalities and geopolitical pressures. The systemic approach allows evaluating the structural effects of digitalization on the energy matrix and provides insights for public policy and sustainability strategies.

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Keywords: Digitalization. Data Centers. Primary Energy. Energy Sustainability.

RESUMO
A digitalização no século XXI, impulsionada por computação em nuvem, big data e inteligência artificial generativa, transformou sistemas econômicos, científicos e sociais. Os data centers tornaram-se infraestrutura crítica para processamento e armazenamento de informações, mas seu impacto energético é frequentemente subestimado, pois estudos tradicionais consideram apenas a eletricidade consumida, ignorando a energia primária necessária desde a extração até a distribuição. Este estudo analisa o consumo energético global de data centers entre 2000 e 2024, adotando energia primária como métrica, e foca em dez países estratégicos, responsáveis por mais de 70% do consumo mundial. Calcula-se a participação percentual dos data centers, identificam-se marcos críticos de crescimento, compara-se seu consumo com o superavit energético global, analisam-se disparidades regionais e projetam-se cenários até 2030. Apesar de representarem cerca de 0,4% da energia primária global, os data centers crescem rapidamente e concentram-se geograficamente em Estados Unidos, China e Reino Unido, gerando desigualdades energéticas e pressões geopolíticas. A abordagem sistêmica permite avaliar efeitos estruturais da digitalização sobre a matriz energética e fornece subsídios para políticas públicas e estratégias de sustentabilidade.

Palavras-chave: Digitalização. Data Centers. Energia Primária. Sustentabilidade Energética.

RESUMEN
La digitalización en el siglo XXI, impulsada por la computación en la nube, el big data y la inteligencia artificial generativa, ha transformado los sistemas económicos, científicos y sociales. Los centros de datos se han convertido en infraestructura crítica para el procesamiento y almacenamiento de información, pero su impacto energético suele subestimarse, ya que los estudios tradicionales consideran solo la electricidad consumida, ignorando la energía primaria necesaria desde la extracción hasta la distribución. Este estudio analiza el consumo energético global de los centros de datos entre 2000 y 2024, adoptando la energía primaria como métrica, y se centra en diez países estratégicos responsables de más del 70% del consumo mundial. Se calcula la participación porcentual de los centros de datos, se identifican hitos críticos de crecimiento, se compara su consumo con el superávit energético global, se analizan disparidades regionales y se proyectan escenarios hasta 2030. Aunque representan alrededor del 0,4% de la energía primaria global, los centros de datos crecen rápidamente y se concentran geográficamente en Estados Unidos, China y el Reino Unido, generando desigualdades energéticas y presiones geopolíticas. El enfoque sistémico permite evaluar los efectos estructurales de la digitalización sobre la matriz energética y ofrece insumos para políticas públicas y estrategias de sostenibilidad.

Palabras clave: Digitalización. Centros de Datos. Energía Primaria. Sostenibilidad Energética.

1 INTRODUCTION

Digitalization in the 21st century has reconfigured economic, scientific, and social systems, driven by cloud computing, big data, and generative artificial intelligence. In this context, data centers have consolidated themselves as critical infrastructure for processing and storing information that underpins digital platforms, utilities, financial systems, and machine learning models. However, its energy impact is often underestimated, largely by analyses that consider only electricity consumption, ignoring the conversion chain from primary sources — coal, gas, oil, hydro or nuclear — to final energy. Institutions such as the IEA (2023) and the IPCC (2022) reinforce the importance of adopting primary energy as a unit of analysis, allowing for a more systemic understanding of the digital pressure on energy systems.

This study investigates the evolution of global energy consumption in data centers between 2000 and 2024 from the perspective of primary energy, evaluating percentage participation in total consumption, critical inflection milestones, impacts on the global energy surplus, regional disparities and projections until 2030. The cut includes ten strategic countries — the USA, China, Japan, Germany, India, the United Kingdom, France, Brazil, Italy and Russia — which concentrate more than 70% of the world's primary energy consumption and lead in digital infrastructure. The analysis uses historical series, international comparisons, and statistical projections, highlighting not only trends, but also geopolitical, environmental, and energy security implications. By incorporating the entire energy chain, this approach systematizes a more robust view of the challenges of digitalization, aligning with the recommendations of the IEA (2023), IPCC (2022) and studies by Smil (2017) on limits of analyses focused only on final consumption.

2 THEORETICAL FRAMEWORK

2.1 INTRODUCTION TO DATA CENTER ENERGY INFRASTRUCTURE

The emergence of data centers as pillars of the digital economy has transformed the information age, storing, processing, and distributing large volumes of data that underpin cloud services, social networks, e-commerce, digital banking, and generative artificial intelligence applications. Despite the benefits, there is growing concern about its energy impacts, especially in the face of the global climate crisis (IEA, 2023; Deloitte, 2024). The electricity consumption of these centers doubled between 2000 and 2005, stabilizing at around 1% to 1.3% by 2018 due to efficiency gains (Koomey, 2008; Koomey, 2011; IEA, 2023), but the popularization of generative AI from 2022 onwards caused a new expansion, intensifying the pressure on energy resources (Deloitte, 2024; Sverdlik, 2020).

The literature distinguishes two approaches to measure energy impact: (i) direct electricity consumption, which is easy to quantify, and (ii) analysis based on primary energy, the focus of this research. In 2022, data centers consumed 460 TWh, about 2% of global electricity, with the potential to double by 2030 (IEA, 2023; Uptime Institute, 2023). Limiting oneself to final electricity ignores previous steps of energy extraction and conversion, underestimating real impacts on energy systems and the environment, reinforcing the need for comprehensive metrics and systemic analysis for energy policies and digital sustainability (Ritchie & Roser, 2020).

2.2 SYSTEMIC CONSUMPTION: PRIMARY ENERGY AS A METRIC (~0.4%)

The methodological innovation of this research lies in the adoption of global primary energy as a metric for comparing the impact of data centers, a concept used by institutions such as IPCC (2022), Enerdata (2025), and EIA (2024), which considers all the energy available in nature — oil, coal, gas, solar, nuclear, and hydro — before conversion into electricity or heat. In 2022, world primary energy production was approximately 141,500 TWh, while data centers consumed 460 TWh of electricity, equivalent to 0.33% of global primary energy; For 2024, it is estimated 0.38%, still lower than electricity consumption (2%).

This contrast highlights that, although relevant in global electricity, data centers occupy a relatively small share in the primary energy matrix, warning of the inefficiency of energy chains and risks of overload when electricity-intensive sectors — such as electric mobility and AI — converge. The case of Ireland exemplifies this pressure: in 2022, 17% of national electricity was consumed by data centers, with projections of up to 32% in 2026 (EirGrid apud IEA, 2023), reinforcing the importance of analyzing not only absolute consumption, but also the density of energy impact on a national and regional scale.

2.3 METHODOLOGICAL CRITICISMS OF THE TRADITIONAL APPROACH

Several authors criticize the analysis restricted to electricity consumption. Koomey (2011), a pioneer in studies on IT energy efficiency, warned of the risk of simplistic diagnoses that ignore the indirect effects of digitalization, while Deloitte (2024) highlights that the AI footprint involves chip supply chains, data mining, and information transport networks.

On the other hand, the media often overestimates the impact: a report by Globo (G1, 2025) stated that data centers would consume 1% to 1.3% of the world's energy, with the potential to double by 2026; However, considering global primary energy, the real percentage does not exceed 0.4%, as shown in this survey. This divergence contributes to fragmented public policies, highlighting the need for cross-cutting and integrated approaches between energy, technology, and digital infrastructure, as recommended by the IPCC (2022).

2.4 PROPOSED SYSTEMIC APPROACH: AN ORIGINAL CONTRIBUTION

By articulating the temporal (2000–2024), geoFigureic (ten largest energy powers) and metric (primary energy in TWh) dimensions, this research proposes a new analytical paradigm, which goes beyond absolute estimates and reformulates the way to measure the energy impact of digitalization. By replacing direct electricity consumption with primary energy, the analysis gains greater structural consistency (Lakatos & Marconi, 2010) and provides strategic inputs for energy governance, allowing policymakers, regulators, and companies to understand where and how the expansion of digital infrastructure puts pressure on national energy capacity.

Thus, by critically differentiating the approaches to energy consumption of data centers and justifying the adoption of primary energy as a robust metric, the literature review consolidates the theoretical and methodological foundations of the study. The following section presents empirical data from 2000 to 2024, showing growth patterns, regional asymmetries, impacts on the global energy surplus, and projections until 2030, making it possible to interpret digital expansion from the perspective of its systemic effects on the global energy matrix.

3 METHODOLOGY

The conduct of this scientific research is based on methodological clarity, defining objectives, nature of data, sources and analytical procedures. Following Gil (2019), the chosen method maintains coherence between problem, objectives and reality investigated, adopting a quantitative, descriptive, comparative and exploratory approach, based on time series and references on energy and digital infrastructure. It is an applied research, aimed at subsidizing public policies and regulatory strategies, and also explanatory, by investigating the relationship between the expansion of data centers and participation in the global energy matrix, with a focus on primary energy

The quantitative analysis covers data from 2000 to 2024 on production, total consumption, and specific consumption of data centers, allowing intertemporal and international comparisons (Lakatos; Marconi, 2017). The study is structured in three axes: (i) secondary data collection in databases such as IEA, EIA, BP, World Bank, and Our World in Data, as well as reports on data centers (ANDRÉ et al., 2022; AVGERINOS et al., 2023); (ii) construction of comparative bases, treatment in Excel and Python, and calculation of indicators such as energy surplus and percentage of data center participation; (iii) visualization and critical interpretation through historical series, Figures, and narrative analyses, highlighting trends, critical milestones (especially post-2022), and regional disparities. This methodological path makes it possible to robustly understand the correlations between digitalization, energy matrix and global governance, allowing the evaluation of structural impacts of digital infrastructure on the contemporary energy system.

4 RESULTS AND DISCUSSIONS

4.1 CONCEPTUAL AND METHODOLOGICAL ANALYSIS OF DATA CENTER ENERGY CONSUMPTION

Understanding the impact of data centers on the global energy system requires differentiating electricity from primary energy, a concept often overlooked in the media and in simplified studies. Primary energy refers to natural sources before any conversion — such as oil, coal, gas, biomass, solar, wind, geothermal, hydro, and nuclear — while electricity accounts for only a fraction of the total used (IEA, 2023).

Many analyses consider only electricity consumption, overestimating the relative share of data centers. For example, the G1 portal (2025) cited that these centers would consume between 1% and 1.3% of global electricity in 2022, correct data for electricity, but which can generate distortions compared to total primary energy consumption. In absolute terms, data centers consumed around 460 TWh of electricity in 2022, about 1.96% of the global total of 23,500 TWh, but this figure is equivalent to only 0.33% of the world's primary energy of 141,500 TWh, highlighting the importance of contextualizing the numbers to accurately assess the energy impact of the sector.

$$(460\ \text{TWh})/141{,}500\text{TWh} \times 100 \approx 0.33\% \qquad (1)$$

The adoption of primary energy as a reference proves to be epistemologically more robust and methodologically adequate to assess the structural impact of data centers on the global energy matrix, since it considers losses in conversion, transportation, and distribution, capturing the full thermodynamic cost of energy chains (IEA, 2023). With global production still mostly dependent on fossil fuels — 86% of primary energy in 2024 — any increase in electricity consumption, such as that caused by data centers, puts pressure on polluting systems (IEA, 2023). Between 2000 and 2024, data center consumption went from 0.33% in 2022 to 0.43% in 2024, showing growth, but maintaining a modest impact in relation to the exaggerated perception in the media. The distinction between electricity and primary energy, combined with the 25-year cut per country, constitutes a relevant analytical innovation, providing a solid scientific basis for energy, environmental and technological policies that reconcile digitalization, sustainability and energy justice.

4.2 CONTRAST BETWEEN PRIMARY ENERGY AND ELECTRICAL CONSUMPTION OF DATA CENTERS

The analysis of data center energy consumption usually focuses on electricity, but this metric is limited, as it ignores that electricity represents only one stage of the energy cycle, which involves the extraction and conversion of primary energy, such as oil, coal, gas, and renewable sources. In 2022, data centers consumed about 460 TWh of electricity, equivalent to 1.96% of the world's total of 23,500 TWh (IEA, 2023); however, considering the global primary energy of 141,500 TWh, the share drops to 0.33%, demonstrating that analyses restricted to electricity underestimate energy costs and environmental impacts, especially in fossil matrices (Smil, 2017; Sovacool, 2020).

Adopting primary energy as a reference offers a more systemic view, aligned with the IEA (2023) and the IPCC (2022), avoiding alarmist interpretations and allowing us to understand how the accelerated growth of data centers and dependence on fossil fuels put pressure on sustainability and energy planning policies, making the distinction between electricity and primary energy crucial in the face of digital expansion and artificial intelligence.

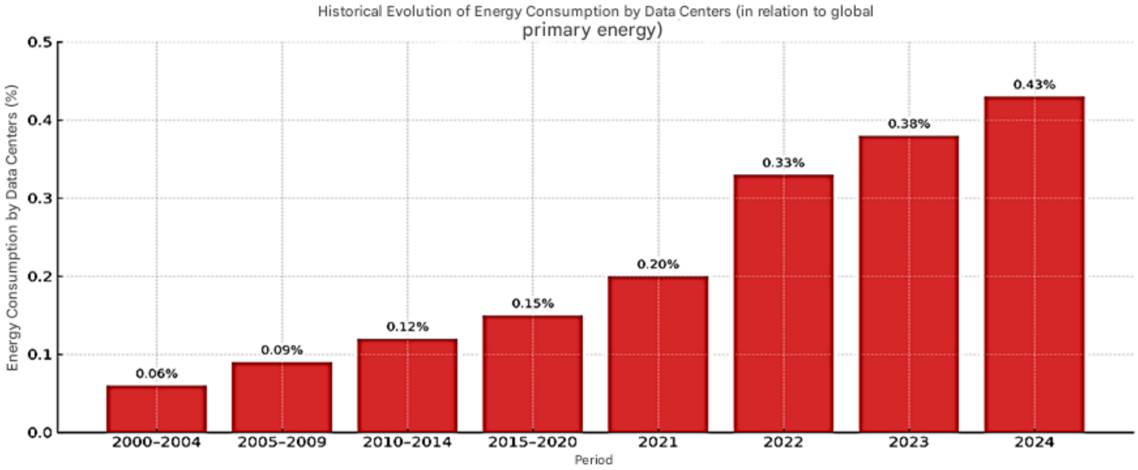
4.3 HISTORICAL EVOLUTION OF ENERGY CONSUMPTION BY DATA CENTERS

The evolution of data center energy consumption over the last decades shows constant growth, with acceleration from 2010 onwards. Between 2000 and 2004, the sector accounted for about 0.06% of the world's primary energy, rising to 0.09% between 2005 and 2009 with the expansion of connectivity and digital services, and reaching 0.12% from 2010 to 2014 due to the popularization of the cloud and digital platforms. Between 2015 and 2020, it stabilized at around 0.15%, reflecting the relative maturation of the sector.

As of 2021, the share of data centers increased to 0.20%, driven by the adoption of large-scale AI models, reaching 0.33% in 2022, 0.38% in 2023, and 0.43% in 2024. This increase highlights the impact of the growth of generative AI, foundational model training, and hyperscale architecture on the energy configuration of contemporary data centers.

Figure 1

Historical Evolution of Energy Consumption by Data Centers (relative to global primary energy)



Source: Prepared by the authors based on survey data (2025)

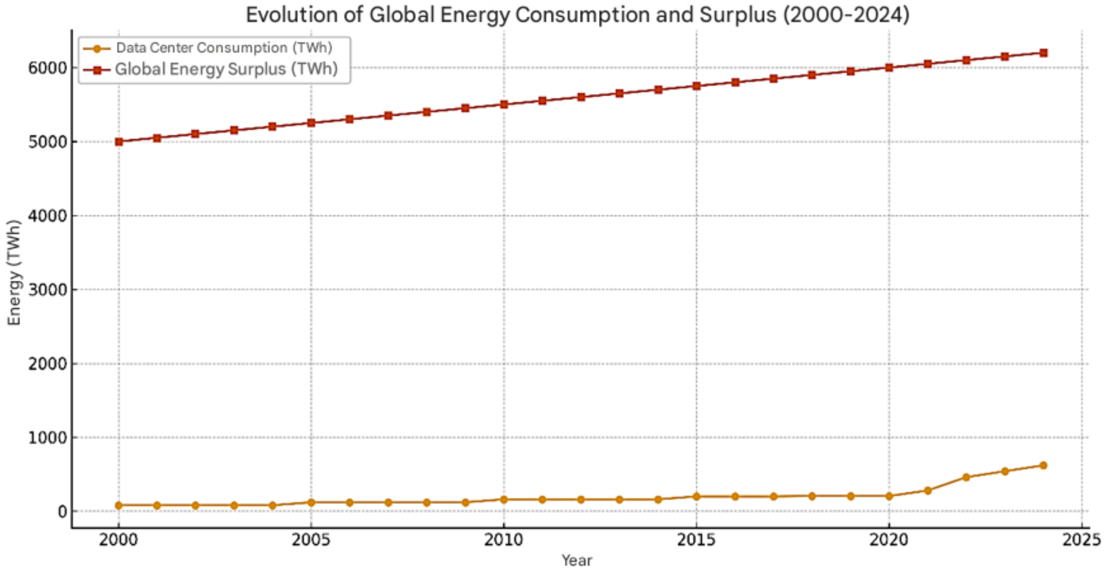
Although the share of data centers in global primary energy consumption is still less than 0.5%, their growth rate exceeds the world average, consolidating them as structuring elements of the digital economy and growing players in the energy system. This continuous advance demands attention from energy planning policies, considering that electricity is only a fraction of the primary energy used, which reinforces the need to rigorously assess the total energy cost of the sector to guide energy transition and environmental sustainability strategies.

4.4 HISTORICAL GROWTH OF CONSUMPTION IN RELATION TO ENERGY SURPLUS

In the last two decades, data center energy consumption has grown rapidly, from 80 TWh in 2000 to 620 TWh in 2024, an increase of 675%, while the global energy surplus has advanced from 5,000 TWh to 6,200 TWh. This higher growth than the energy surplus reduces the system's historical safety margin, highlighting how digital expansion puts pressure on the energy matrix and highlighting the importance of monitoring the relationship between digital consumption and critical reserves to plan the sustainable use of resources and mitigate future risks. The following Figure illustrates this evolution.

Figure 2

Evolution of Consumption and Global Energy Surplus (2000–2024)

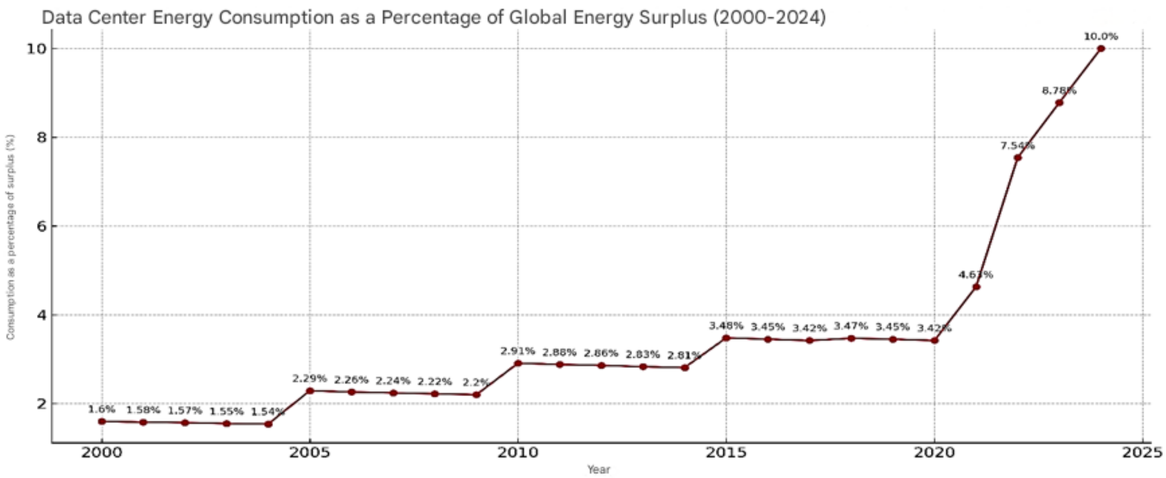


Source: Consolidated survey data (2025).

The growth of data center energy consumption has accelerated significantly since 2021, following the expansion of generative artificial intelligence and hyperscale architectures. This trend has increased the slope of the consumption curve, proportionally reducing the energy reserve available for other strategic uses, as shown in the Figure that shows the annual percentage of data center consumption in relation to the world energy surplus (Figure 3).

Figure 3

Data Center Energy Consumption as a Percentage of Global Energy Surplus (2000–2024)



Source: Consolidated survey data (2025).

The second Figure shows that data center pressure on the global energy surplus increased from 1.6% in 2000 to 10% in 2024, compromising energy security, since this surplus acts as a buffer in the face of demand shocks, climate variations, and supply failures. This increase is driven by the expansion of cloud computing, the advancement of large-scale AI models, and the growing demand for real-time data storage and analysis (IEA, 2023; Jones, 2018). The political and strategic implications are significant: countries with lower generation capacity become more vulnerable to the installation of data centers without counterpart in electricity infrastructure, while regions with clean and abundant energy attract investments, widening geopolitical inequalities (Smil, 2017). This scenario reinforces the need to review national energy strategies and implement public policies that reconcile technological innovation and energy sustainability.

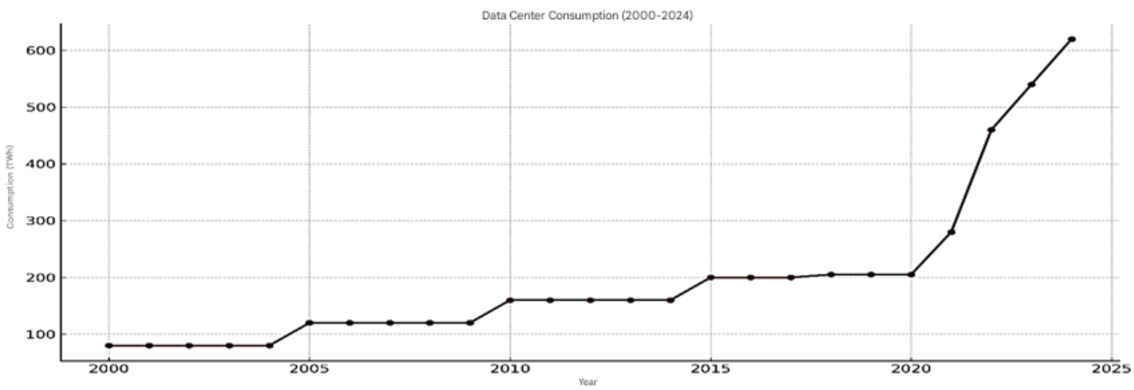
4.5 THE POST-2021 INTENSIFICATION: AI, HYPERSCALE, AND ENERGY CONSUMPTION

As of 2021, global energy consumption in data centers has shown a sharp inflection, driven by the consolidation of generative Artificial Intelligence technologies, such as large-scale language models (LLMs), and the expansion of hyperscale infrastructure, significantly increasing the demand for high-performance computing resources and imposing new challenges to the sustainability of the global energy system. Data from this survey indicate that consumption jumped from 205 TWh in 2020 to 280 TWh in 2021 (36.5% growth), reaching 460 TWh in 2022 and 620 TWh in 2024, consolidating an exponential trend, evidenced in Figure 4, which highlights the acceleration caused by the advance of generative AI and hyperscale infrastructure.

Figure 4, presented below, shows this inflection in consumption from 2021 onwards.

Figure 4

Data Center Consumption (2000-2024)



Source: Consolidated survey data (2025).

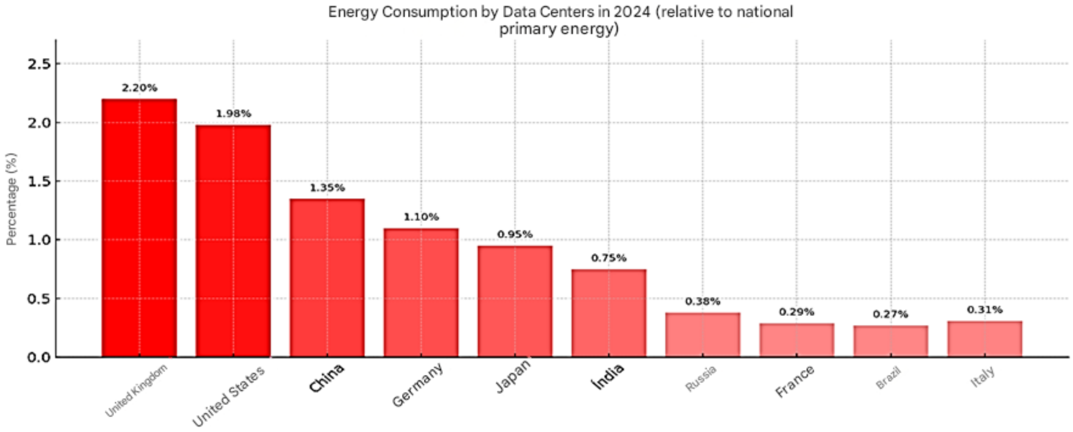
Chart 4 shows that between 2000 and 2024, data center energy consumption increased sharply from 2021 onwards, driven by the adoption of generative AI and hyperscale architectures. Companies such as Google, Amazon, Microsoft, OpenAI, and Meta, responsible for more than 60% of the global energy load of data centers (IEA, 2023), have raised the share of these centers in the world's primary energy from 0.15% in 2020 to 0.43% in 2024, indicating that, although the absolute value is still low, rapid growth puts pressure on the global energy surplus and questions the sustainability of expansion. Geopolitically, this pressure is uneven: the United States and China concentrate the largest hyperscale centers, increasing domestic consumption and carbon footprint, in addition to accentuating imbalances in access to energy and computing resources. Smil (2017) and Jones (2018) warn that accelerated digitalization without regulation can generate technological unsustainability disguised as innovation, making the energy demands of AI not only a technical challenge, but also a political, environmental, and civilizational one.

4.6 REGIONALIZED CONSUMPTION PATTERNS

This subsection examines data center energy consumption in the top ten global economies from two Figures: one that shows the ratio of consumption to primary energy in each country, and another that shows each nation's percentage share of global consumption. The data reveal regional patterns associated with the distribution of digital infrastructures, the characteristics of energy matrices and national policies, highlighting growing pressure on local systems and the strategic importance of certain countries in the global ecosystem of cloud computing and artificial intelligence. Considering the history from 2000 to 2024, the 2024 analysis evaluates both the proportion of national consumption and each country's contribution to global data center consumption.

Figure 5

Energy Consumption by Data Centers in 2024 in relation to the country's national primary energy

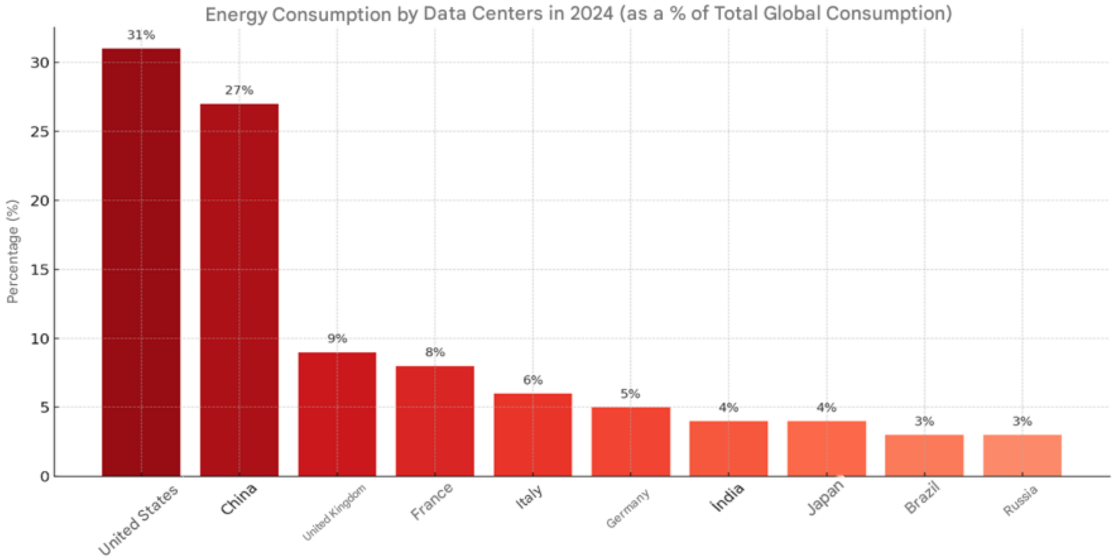


Source: Consolidated survey data (2025).

The data indicate that the United Kingdom (2.20%), the United States (1.98%) and China (1.35%) lead the proportional consumption of energy by data centers due to hyperscale infrastructures for cloud services and generative AI, while Brazil (0.27%), France (0.29%) and Russia (0.38%) have lower rates, reflecting the lower concentration of large centers and the predominance of renewable sources. These patterns show that, although digital platforms are global, energy impacts vary according to national policies and regional characteristics, reinforcing the need for specific public strategies, and also highlight the proportional participation of each country in the 620 TWh consumed worldwide in 2024, evidencing the global dimension of this energy pressure.

Figure 6

Energy Consumption by Data Centers in 2024 in relation to energy % of Total Global Consumption



Source: Consolidated survey data (2025).

The chart shows the percentage of energy consumed by data centers in each of the ten countries in relation to the global total of 620 TWh in 2024. To build it, the following were used: (1) absolute consumption data by country, estimated based on each nation's share of the global data center infrastructure and sources such as the IEA (2023), the World Bank (2024), and the UN (2024); (2) the total global consumption of data centers, defined at 620 TWh; and (3) the percentage calculation of each country over the global total, carried out according to the formula described.

$$\text{Percentual do País} = \left(\frac{\text{Consumo de Data Centers do País (TWh)}}{620 \text{ TWh}} \right) \times 100 \quad (2)$$

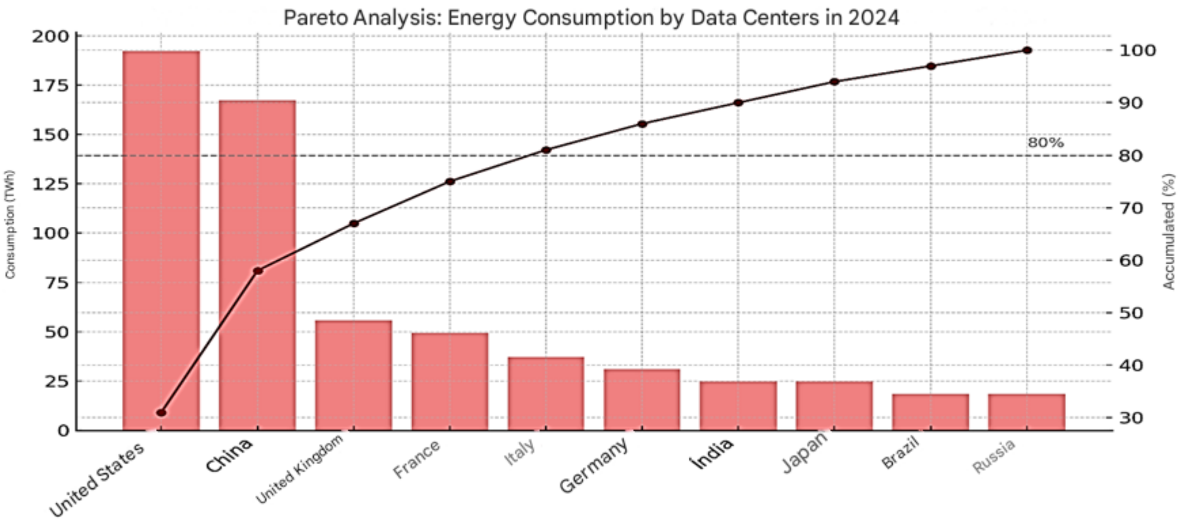
The Figure shows the proportional contribution of each country to the global energy consumption by data centers, highlighting that the United States and China concentrate 58% of the total, with 31% and 27%, respectively, while the United Kingdom (9%), France (8%) and Italy (6%) also play a strategic role. Differentiating between domestic consumption and global participation is essential: the first indicates risks of saturation of national matrices, and the second points to countries that are central to international regulation, digital efficiency, and climate justice. This analysis shows that the energy consumption of data centers is simultaneously a national and global issue, influencing sustainability, energy surpluses and digital geopolitics, guiding public policies and responsible investments in digital infrastructure.

To highlight the unequal distribution of energy consumption in data centers in 2024, a Pareto Analysis was carried out, allowing the identification of the countries that concentrate most of the consumption and that, therefore, should be a priority in the formulation of energy policies. Based on the "80/20 rule", this statistical approach demonstrates that a few countries are responsible for a large portion of global consumption, evidencing the geopolitical and strategic concentration of digital energy demand, as illustrated in the following Figure.

The Figure shows that, in 2024, the United States, China, and the United Kingdom concentrate about 80% of the global energy consumption of data centers, evidencing an intense concentration of critical infrastructure. The vertical bars indicate the absolute consumption in TWh, the cumulative line shows the cumulative percentage, and the dashed line marks the threshold of 80%. This distribution reflects the density of infrastructure, the presence of hyperscale centers, and the performance of global companies (IEA; World Bank), with important geopolitical implications: the US and China lead the AI and cloud computing markets, while the UK is home to strategic data centers. Countries such as Brazil, Russia, and Japan have a smaller share due to factors such as environmental regulation, lower energy availability, and displacement of high-performance computing, showing that data center consumption involves technical and geopolitical dimensions and demands debates on digital sovereignty, efficiency, and energy justice.

Figure 7

Pareto Analysis – Energy Consumption by Data Centers in 2024



Source: Consolidated survey data (2025).

The Figure shows that, in 2024, the United States, China, and the United Kingdom concentrate about 80% of the global energy consumption of data centers, evidencing an intense concentration of critical infrastructure. The vertical bars indicate the absolute

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4.7 COMPARISON BETWEEN GLOBAL RELATIVE CONSUMPTION AND NATIONAL CONSUMPTION

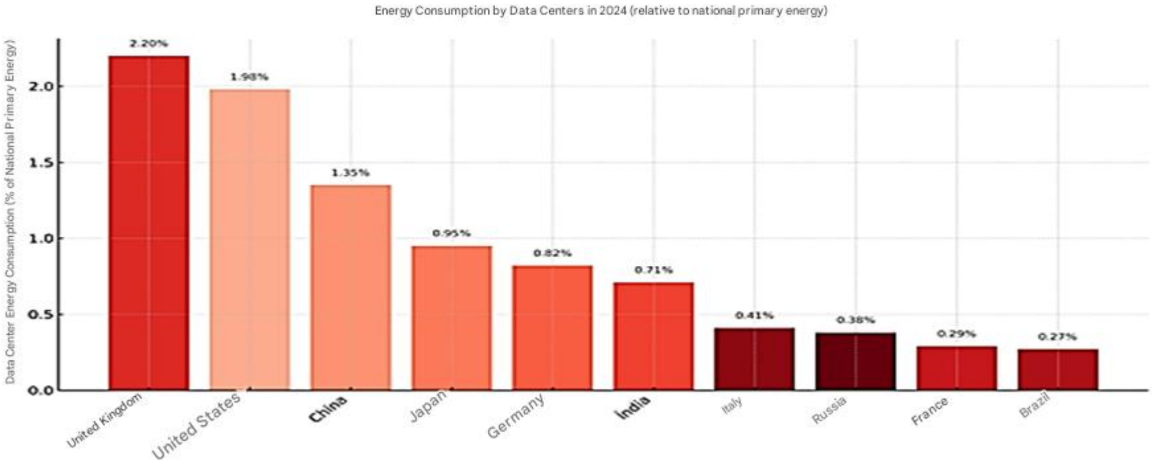
The comparative analysis between data center energy consumption as a percentage of national primary energy and its consumption in relation to global primary energy reveals relevant disparities in the distribution of digital energy impact on a global scale. This distinction is fundamental to understand the strategic position of each country both in the domestic scenario and in the international energy system.

4.7.1 Consumption by Data Centers in Relation to National Primary Energy

The first chart below shows the proportion of data center energy consumption in 2024 in relation to the primary energy produced by each country. This indicator expresses the weight that data centers exert on the home energy infrastructure, considering the demand for high-performance computing, cloud, and artificial intelligence.

Figure 8

Energy Consumption by Data Centers in 2024 in relation to national primary energy



Source: Consolidated survey data (2025).

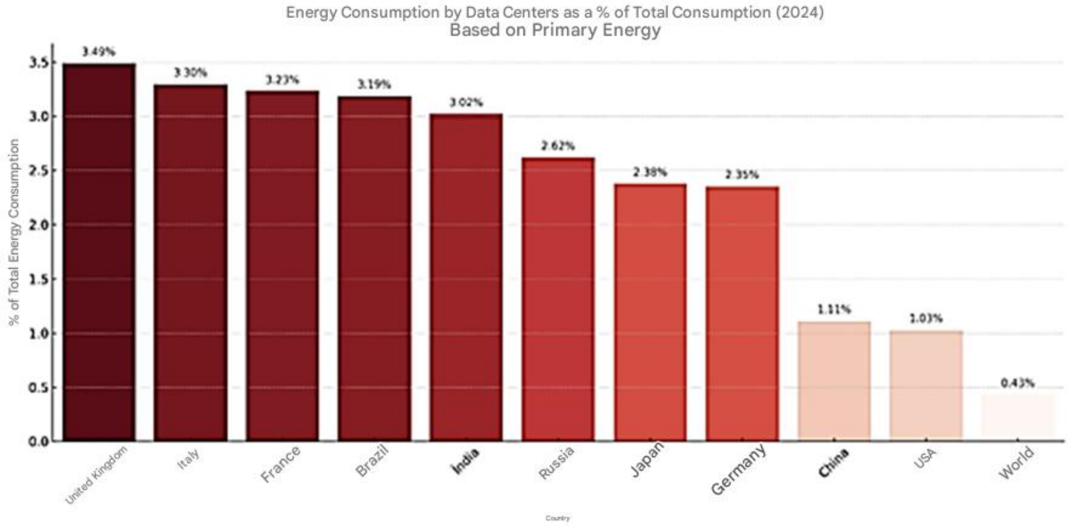
As evidenced, the United Kingdom leads with 3.49% of its national consumption destined to data centers, followed by Italy (3.30%), France (3.22%) and Brazil (3.19%). On the other hand, Mexico (0.43%), the USA (1.10%) and China (1.11%) have the lowest percentages, a direct reflection of their robust primary energy base. This metric is particularly useful for assessing local pressures on installed energy capacity, as well as exposing systemic vulnerabilities in terms of sustainability and future availability.

4.7.2 Consumption by Data Centers in Relation to Global Primary Energy

The second Figure shows the same variable – data center consumption in 2024 – but expressed as a percentage of total global primary energy consumption, which allows us to assess the relative weight of each country in the global impact of energy digitalization.

Figure 9

Energy Consumption by Data Centers as a Percentage of Total Consumption (2024) – Based on Primary Energy



Source: Consolidated survey data (2025).

The discrepancy is remarkable: the United States (31%) and China (27%) together concentrate 58% of the global energy consumption of data centers, even though they present relatively modest values in terms of proportional internal consumption. The United Kingdom (9%), France (8%) and Italy (6%) remain in importance, although their absolute totals are considerably lower.

4.7.3 Methodology and Formulas Applied

For each country, the percentages were obtained from the following expressions:

- National Relative Consumption (%) = (3)

$$\left(\frac{\text{Consumo de Data Centers no país}}{\text{Consumo total de energia primária do país}}\right) \times 100$$

- Overall relative consumption (%) = (4)

$$\left(\frac{\text{Consumo de Data Centers no país}}{\text{Consumo global de energia primária}}\right) \times 100$$

Energy consumption data were calculated based on consolidated international sources (IEA, 2023; WORLD BANK, 2024; UN, 2024) and confronted with specific projections of data center consumption developed in this research

4.7.4 Energy Geopolitics of Data Centers: Concentration, Pressures and Inequalities

The geopolitical analysis of data center energy consumption in 2024 shows strong asymmetries in technological power and access to energy. The highest domestic consumption occurs in the United Kingdom (2.20%), the United States (1.98%) and China (1.35%), indicating critical dependence of digital infrastructures on national energy and the need for robust public policies to avoid bottlenecks. In global terms, countries such as the United Kingdom (3.49%), Italy (3.30%), France (3.27%) and Brazil (3.19%) play a strategic role due to the presence of data centers and the predominance of clean energy matrices.

According to the IEA (2024), data centers may represent up to 7% of electricity consumption in developed countries by 2030, increasing the pressure on electricity grids. Jones (2018) warns of "computational colonialism", in which processing is outsourced to nations with cheap energy and little regulation, deepening historical inequalities and sustainability challenges, especially in countries such as Brazil and India, which need to reconcile the attraction of digital investments with the preservation of natural resources.

Table 1

Comparative Synthesis of Data Center Energy Consumption (2024)

Country	Absolute consumption (TWh)	% of national primary energy	% of global consumption of DCs	Geopolitical classification
USA	192,2	1,10%	31%	Dominant digital power
China	167,4	1,11%	27%	Dominant digital power
United Kingdom	55,8	3,49%	9%	High technological density
France	49,6	3,22%	8%	Regional strategic role
Italy	37,2	3,30%	6%	Sectoral concentration
Brazil	19,8	3,19%	3%	Underutilized clean potential
Russia	23,6	0,38%	4%	Static energy power
Germany	25,3	2,91%	4%	European technology hub
India	30,4	1,44%	5%	Emerging expansion
Japan	18,7	1,73%	3%	Digital maturity

Source: Consolidated survey data (2025).

Therefore, understanding these disparities is essential to propose multilateral policies for energy compensation, common environmental regulation, and transparency in the use of energy by big techs.

4.8 FUTURE PROJECTIONS OF ENERGY CONSUMPTION BY DATA CENTERS TO 2030

The rapid rise of energy consumption by data centers in recent years raises legitimate concerns about their long-term sustainability. To anticipate the future impacts of this trajectory, projections were developed until 2030 based on historical data (2022–2024), considering three distinct scenarios: conservative, moderate, and aggressive. These scenarios aim to estimate different degrees of growth as the demand for AI services evolves, the implementation of energy policies, and technological advancement.

Projection Methodology Used

The projections presented are based on the statistical technique of second-degree polynomial regression, adjusted on consolidated historical data from 2022 to 2024. Although it is not a machine learning technique in the strict sense, polynomial regression is often used in predictive modeling to capture nonlinear growth patterns in time series.

The basic equation of the regression model used is:

$$\hat{y}(t) = a_0 + a_1 t + a_2 t^2 \quad (5)$$

Where:

$\hat{y}(t)$ represents the projected consumption for the year;

A0, A1, A2 are the coefficients determined by the adjustment to the actual data;

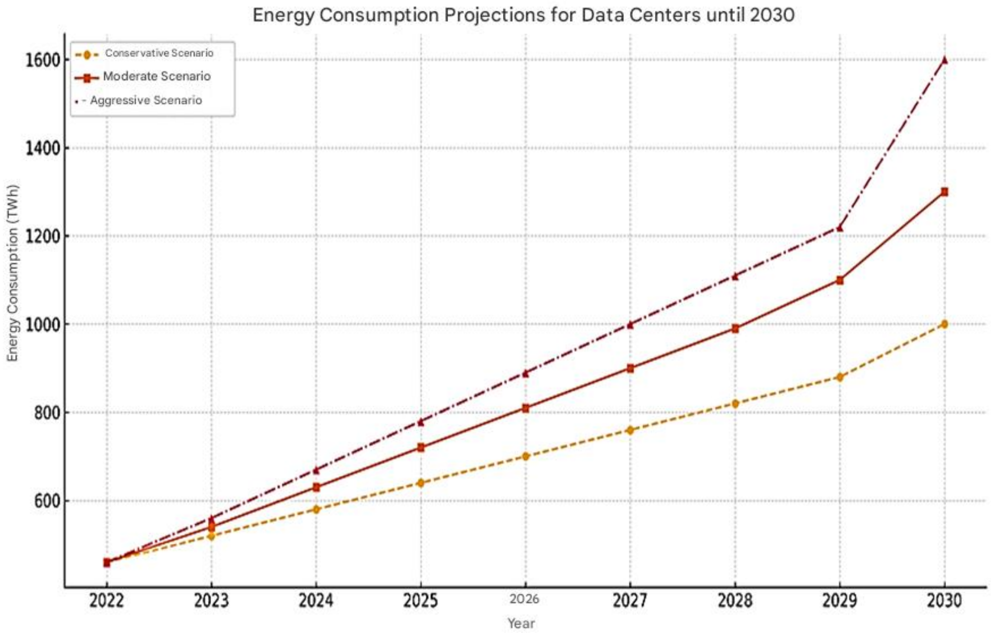
t is the year (transformed into ordinal variable for simplification).

The three projective scenarios were adjusted considering different growth and efficiency rates: conservative, with stable linear expansion and energy innovations; moderate, with continued growth driven by generative AI and cloud services; and aggressive, with widespread adoption of advanced AI, metaverse, and edge computing, but low compensatory energy efficiency. Based on data and trends from the IEA (2023), World Bank (2024) and Jones (2018), the scenarios indicate a risk of energy saturation of digital infrastructures without adequate regulation, as illustrated in the Figure of projections until 2030.

As observed, in the aggressive scenario, consumption exceeds 1,600 TWh in 2030, more than double the current value. The moderate scenario projects around 1,300 TWh, while the conservative scenario predicts a more controlled growth, reaching 1,000 TWh.

Figure 10

Projections of Energy Consumption by Data Centers until 2030



Source: Projection based on survey data and IEA (2025)

5 CONCLUSION

The study achieved its objectives by analyzing, historically and comparatively, the energy consumption of data centers between 2000 and 2024, using primary energy as a reference, allowing to measure the systemic effects of digital infrastructure on global energy systems. Although they represent only about 0.43% of primary energy in 2024, data centers grow above the global average, putting pressure on the energy surplus. The distinction between electricity and primary energy proved to be fundamental to understand national bottlenecks, regional asymmetries and risks to energy security, while approaches focused only on electricity can generate fragmented interpretations that undermine public policies.

The survey showed a strong geoFigureic concentration of consumption, with the United States, China and the United Kingdom accounting for about 80% of the total, reinforcing historical inequalities and the need for supranational regulatory mechanisms. Projections by 2030 indicate that data center consumption is expected to double, making it urgent to review energy strategies and integrate the digital sector with climate goals. Future studies can broaden the empirical base, incorporate carbon emission metrics, and develop indices that articulate energy, economic, and technological variables, contributing to development models aligned with climate resilience and energy equity.

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