Big Tech: An Industry with an Increasingly High Energy-Revenue Intensity

Lieven Eeckhout
Ghent University, Belgium

***Abstract*—This paper analyzes the carbon footprint of the Big Tech industry through the lens of the Kaya identity which breaks down the world's carbon footprint in its four contributing factors: population, affluence or Gross Domestic Product (GDP) per capita, energy intensity (energy consumption per unit of GDP), and carbon intensity (carbon emissions per unit of energy). While energy intensity decreases globally due to efficiency improvements and a transition towards an increasingly service-based economy, this paper reports that Big Tech, the quintessential service-based industry, goes the opposite way and in fact is an actor with an increasingly high energy-revenue intensity, i.e., increasingly high energy consumption per gross revenue. Despite the fact that the Big Tech industry procures carbon-free energy to offset their own environmental footprint, it does not negate Big Tech's increasing contribution to global warming.**

	Location	% of total	GHG emissions (million tons)
	World	100%	52,962.9
1	China	30.1%	15,944.0
2	United States	11.3%	5,960.8
3	India	7.8%	4,133.6
4	European Union	6.1%	3,221.8
5	Russia	5.0%	2,672.0
6	Brazil	2.5%	1,300.2
7	Indonesia	2.3%	1,200.2
8	Japan	2.0%	1,041.0
9	Iran	1.9%	996.8
10	Saudi Arabia	1.5%	805.2
11	Canada	1.4%	747.7
...			
	International shipping	1.4%	746.9
	International aviation	0.9%	498.2

TABLE I: List of countries by carbon emissions in 2023 [21].

I. Introduction

Sustainability in general and global warming in particular pose a major challenge for our generation. Information and communication technology (ICT) is a — surprisingly perhaps — large contributor to global warming as previously reported by Freitag et al. [23] who state that ICT currently contributes 2.1 to 3.9% of global greenhouse gas (GHG) emissions. While this percentage may seem small, it is not when put into perspective. As illustrated in Table I, if ICT were a country, it would rank among the top-8 most polluting countries in the world [21]. Moreover, ICT contributes to global warming more than international shipping and aviation.

The contribution of ICT to global warming can be decomposed into three major parts, namely consumer electronics, networking, and datacenters, each of which contribute roughly for about one third to ICT's total contribution [23]. Consumer electronics include a variety of devices including smartwatches, smartphones, tablets, laptops, desktop computers, gaming consoles, etc. and show no sign of slowing down in terms of their global emissions, on the contrary [22]. Networking includes both wired and wireless networks forming the backbone for modern-day communication. The datacenter segment includes privately owned and co-located infrastructure as well as hyperscale datacenters, and is perhaps the fastest growing contributor to ICT's GHG emissions. Hyperscalers and co-located datacenters both contribute for about half of the datacenters' global emissions [27].

According to the International Energy Agency (IEA), in 2024, datacenters consumed about 415 terawatt-hours (TWh), or roughly 1.5% of global electricity, mostly concentrated in the United States (US), China and Europe [9]. Projections from the IEA further anticipate this could more than double to 945 TWh by 2030. The US Department of Energy similarly report that, by 2028, datacenter computing will account for 6.7% to 12.0% of the total electricity consumption in the US [26]. In 2023, datacenters already consumed 21% of the total electricity consumption in Ireland [6]. In various regions around the world including Ireland, the Netherlands (Amsterdam), Singapore and the US, an existing/recent moratorium for datacenters has been put into place to conserve electricity needs [20].

The rapid growth in datacenter electricity consumption is largely driven by Artificial Intelligence (AI). Indeed, various Big Tech companies are seeking energy agreements to secure sufficient electricity supply for their datacenters to fuel anticipated AI growth, see for example Microsoft announcing a power purchase agreement to restart a retired 835 megawatt (MW) nuclear facility [8], and Meta recently announcing an up to 6.6 gigawatt (GW) nuclear deal [19].

In this paper we look at the contribution of the five leading Big Tech companies, in particular Microsoft, Apple, Amazon, Google (Alphabet) and Meta (Facebook), through the lens of the Kaya identity which breaks down the world's global emissions in its four contributing factors: population, affluence (gross domestic product or GDP per capita), energy intensity (energy consumed per unit of GDP), and carbon intensity (GHG emissions per unit of energy). Globally, the Kaya identity illustrates that the world's GHG emissions increase because of growth in population and affluence, which is not offset by reductions in energy and carbon intensity. In other words, reductions in energy and carbon intensity fueled by efficiency improvements through an increasingly service-based economy alongside a transition from brown to green energy sources, do not compensate for the steady growth in population and affluence.

More specifically, this paper focuses on the energy-revenue intensity (or energy intensity for short) of the Big Tech industry, or how total energy (electricity) consumption (in TWh) relates to gross revenue (in billions of US dollars). A lower energy-revenue intensity indicates greater efficiency, meaning less electricity is needed for each dollar earned, reflecting high productivity and low environmental footprint. The remarkable conclusion from this analysis is that the Big Tech industry goes against the general trend of reduced energy intensity. While the world's energy intensity decreases at a rate of -1% per year (i.e., general productivity increases and environmental footprint reduces), Big Tech's energy intensity increases by +9.6% per year (i.e., Big Tech's productivity decreases and its environmental footprint increases). This is a significant observation because energy intensity reflects improvements in energy efficiency, technological innovations, and deindustrialization, i.e., transitioning towards a post-industrial, service-oriented economy. In other words, while often considered the quintessential service-based industry, Big Tech is in fact becoming an increasingly energy-intensive sector — a development that is both unexpected and undesired.

The obvious solution for the Big Tech industry to compensate for their increasing energy intensity is to procure carbon-free energy (CFE), which allows them to drastically reduce their own environmental footprint. This allows a company to report market-based GHG emissions as opposed to location-based emissions: market-based emissions equals location-based emissions bound to a geographical boundary and its electricity mix, minus CFE procurement. Unfortunately, because the total amount of green energy is finite, CFE procurement implies that other companies and users cannot purchase green energy, i.e., it is a zero-sum game globally. This suggests that market-based reporting obscures the reality that Big Tech's environmental footprint is increasing, and therefore favors location-based methods to clearly demonstrate the impact of the sector's increased energy intensity.

II. The Kaya Identity

The Kaya identity, formulated by the Japanese energy economist Yoichi Kaya [24], breaks down the global greenhouse gas carbon dioxide (CO_2) emissions as a product of four factors:

$$F = P \times \frac{G}{P} \times \frac{E}{G} \times \frac{F}{E} \tag{1}$$

with F the global CO_2 emissions, P the global human population, G the world's Gross Domestic Product (GDP), and E the global energy consumption. In other words, G/P equals GDP per capita, E/G is energy intensity per unit of GDP, and F/E quantifies carbon intensity or the amount CO_2 emissions per unit of energy consumed. Although the four factors in the Kaya identity cancel out (i.e., mathematically, the equation states $F = F$), it enables computing the world's total emissions using readily available data including population, GDP per capita, energy and carbon intensity. In fact, the Kaya identity is a key formula used by the United Nations' Intergovernmental Panel for Climate Change (IPCC) in their annual 'Special Reports on Emissions Scenarios'.

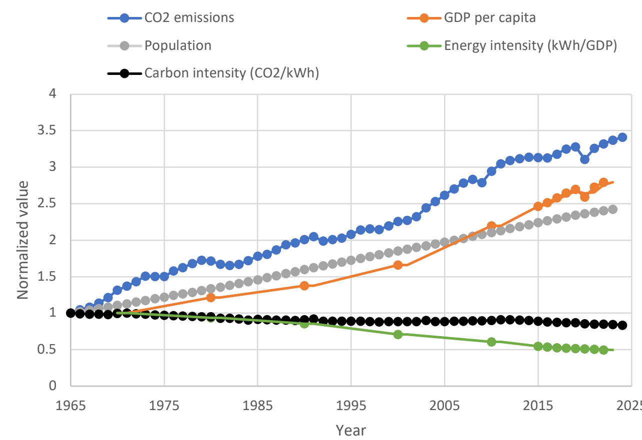

Fig. 1: Quantifying the Kaya identity [12]. *The increase in population and GDP per capita outweighs the decrease in energy and carbon intensity, leading to an overall increase in carbon emissions.*

Figure 1 quantifies the Kaya identity using data obtained from Our World in Data [12], normalized to 1965. Population has grown by +142.7%, and GDP per capita has grown by +179.3% since 1965. In other words, the world population continues to grow and so does average affluence. On the other hand, energy intensity (kWh per GDP) was reduced by -50.1%, while carbon intensity (CO_2 per kWh) was reduced by -16.3%. The reduction in energy intensity reflects energy efficiency improvements, technological innovations, and a shift towards service-based economies. The reduction in carbon intensity is largely attributed to the increased use of green energy sources in the global energy mix.

The Kaya identity clearly illustrates that the decrease in energy and carbon intensity does not compensate for the increase in population and affluence, which leads to a net overall increase in carbon emissions. In other words, improvements in energy and carbon intensity are lagging behind the increase in population and affluence.

To dive deeper into these trends we use the Compound Annual Growth Rate (CAGR), defined as

$$CAGR = \left(\frac{V_t}{V_0}\right)^{1/t} - 1, \tag{2}$$

with V_t the value in year t and V_0 the initial value in reference year 0. We find that the world population is increasing by +0.9% per year, and affluence per capita is increasing by +1.2% per year since 2019.[1] In contrast, energy intensity (kWh per GDP) is decreasing by -1.0%, while carbon intensity is decreasing by -0.7% per year.

[1]We use 2019 as the pre-COVID reference year in this paper.

Year	Microsoft	Apple	Amazon	Google	Meta	Total
2019	125.84	260.17	280.52	161.9	70.70	899.1
2020	143.02	274.52	386.06	182.5	85.97	1,072.1
2021	168.09	365.82	469.82	257.6	117.93	1,379.3
2022	198.27	394.33	513.98	282.8	116.61	1,506.0
2023	211.92	383.29	574.79	307.4	134.90	1,612.3
2024	245.12	391.04	637.96	350.0	164.50	1,788.6
2025	281.72	416.16	*691.33*	*385.5*	*189.46*	1,964.2

TABLE II: Gross revenue (billion USD) by Big Tech. (Estimated values are reported in italics.)

Year	Microsoft	Apple	Amazon	Google	Meta	Total
2019	9.2	2.4	*12.0*	12.8	5.1	41.5
2020	11.3	2.6	*26.0*	15.5	7.2	62.6
2021	14.1	2.9	*33.0*	18.6	9.4	78.0
2022	18.6	3.2	*39.0*	22.4	11.5	94.7
2023	24.0	3.2	*42.8*	25.9	15.3	111.2
2024	30.2	3.8	*47.5*	32.7	*18.0*	132.2
2025	*38.0*	*4.2*	*54.0*	*40.0*	*21.6*	157.8

TABLE III: Energy consumption (TWh) by Big Tech. (Estimated values are reported in italics and obtained using Google Chrome's AI Mode.)

III. Big Tech's Energy Intensity

The Big Tech industry is the leading industry that embodies, par excellence, the shift towards a service-based economy. Table II reports the gross revenue as reported by Macrotrends for the leading five Big Tech companies: Microsoft [18], Apple [15], Amazon [14], Google (Alphabet) [16], Meta (Facebook) [17]. Clearly, Big Tech's revenue has increased dramatically by +218.5% over the past 6 years from 899 billion USD in 2019 to 1,964 billion USD in 2025, which corresponds to a CAGR of +13.9% since 2019.

On the flip side, electricity consumption also increased dramatically, see Table III for Microsoft [2, 13], Apple [3, 4, 10], Amazon, Google (Alphabet) [5, 11], Meta (Facebook) [7]: electricity consumption increased by +380.2% since 2019, which corresponds to a CAGR of +24.9%. Note that most of these numbers were obtained from the companies' sustainability reports except for 2025 (because companies typically publish their sustainability reports in the following year) and Amazon (because Amazon does not typically publish a TWh number in its public sustainability reports) — Google Chrome's AI Mode was used to obtain the reported estimates. Note further that out of the five Big Tech companies, Apple consumes substantially less electricity compared to the other four companies, presumably because Apple does not operate datacenter infrastructure at a scale that is comparable to Microsoft, Amazon, Google and Meta.

Based on these data sources, Figure 2 reports energy-revenue intensity in kWh per US dollar — these values are obtained by dividing the values in Tables III and II, respectively. Energy intensity for the five Big Tech companies increased by +174.1% since 2019 at a CAGR of +9.6%. While the CAGR varies across companies, i.e., Microsoft (+10.7%), Apple (+1.5%), Amazon (+10.6%), Google (+4.6%), and Meta (+7.9%), the annual increase in energy intensity holds true across the industry. This reveals an important insight: *while one would expect modern-day industries to reduce their energy intensity through technology improvements and a shift towards a service-oriented economy, it turns out that the Big Tech industry, which is the quintessential service-based industry, in fact increases its energy intensity! Moreover, the energy intensity increases substantially with a CAGR of +9.6% compared to the world's average energy intensity which is slowly decreasing at a CAGR of -1.0%.* This implies that other industries are reducing their energy intensity at a rate that overcompensates for the increased energy intensity of the Big Tech industry. In other words, the Big Tech industry goes against the world-wide trend of improving energy intensity. The fundamental reason is that the increase in electricity consumption outpaces the increase in revenue, i.e., electricity consumption increases faster than gross revenue. (Note that Big Tech's net income increases faster than electricity consumption, which explains why this is a reasonable grow path from a business perspective.)

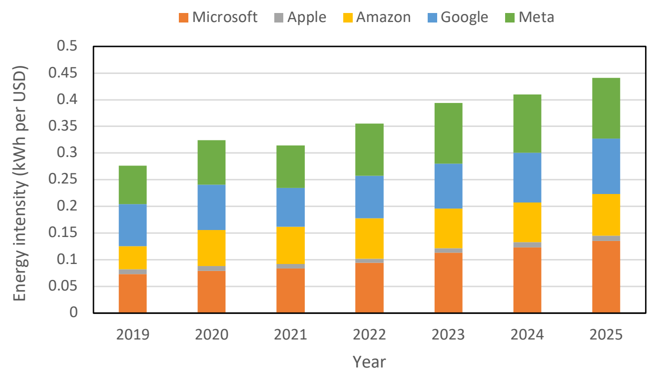

Fig. 2: Energy intensity (kWh per USD) for the Big Tech companies.

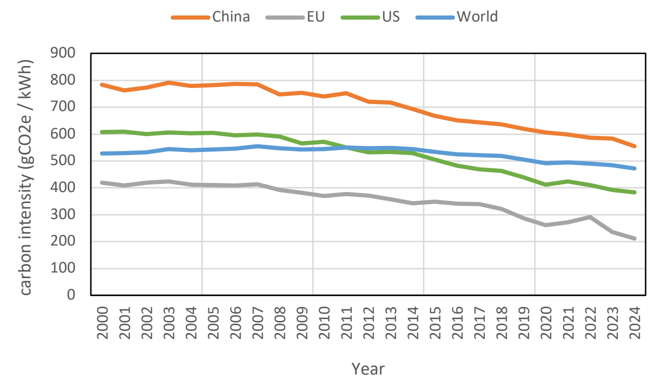

Fig. 3: Carbon intensity of the electricity mix for different regions in the world (gCO2e per kWh).

IV. Green Energy to the Rescue?

The Big Tech industry is well aware of its increasing energy demands and its impact on the environment. As a result, it is increasingly relying on green energy sources. The reality though is that the electricity mix is not transitioning fast enough to counter the increase in energy intensity. Indeed, Figure 3 reports the carbon intensity of the electricity grid in the world, as well as for three regions in the world where datacenters are mostly located, namely the United States, Europe (European Union) and China [1]. Carbon intensity is decreasing globally at a CAGR rate of -1.4% (world)[2], -2.7% (US), -5.9% (EU) and -2.2% (China) since 2019. Fortunately, carbon intensity is improving faster in the regions where datacenters are located compared to the world average.

The above numbers assume so-called *location-based* GHG emissions which are bound to a specific geographic boundary, such as country or a region in the world. These numbers are calculated using the average electricity emissions factor of the specific grid. Big Tech companies, as well as other companies, can (and do!) purchase *carbon-free energy (CFE)* which allows them to reduce their emissions. This is referred to as *market-based* GHG emissions and is equal a company's (or user's) location-based emissions minus the procured carbon-free energy. Schneider et al. [25] report how this allowed Google to bring down its carbon intensity in 2023 from 366 gCO_2e/kWh to 135 gCO_2e/kWh by procuring CFE worth 231 gCO_2e/kWh.

While the CFE procurement mechanism enables companies to reduce their own carbon footprint, it does not lead to a global reduction in carbon emissions. Indeed, the amount of green energy is finite, as reflected in the location-based carbon intensity numbers reported in Figure 3, and hence if certain users or companies are procuring green energy, this implies that there is less green energy left for others to purchase. So while CFE procurement enables Big Tech companies to claim green operation, it does not negate the fact that global emissions is increasing due to the Big Tech industry because of the zero-sum game.

V. Related Work

Structure Research, an independent research and consulting firm with a specific focus on datacenters, provides an analysis [27] in which they extract environmental footprint data from the publicly available Environmental, Social, and Governance (ESG) reports between 2019 and 2024 for 27 datacenter providers and 9 hyperscalers (including the five Big Tech companies included in this paper). The key parameters include scope-1 and scope-2 (location-based) GHG emissions, as well as total and renewable energy use. Some of the key overall conclusions are that total datacenter energy consumption makes up 1.1% of global energy consumption in 2024; total energy usage increased from 178.5 TWh in 2019 to 310.6 TWh in 2024; about half (48%) of the total emissions is attributed to co-located datacenters while the other half (52%) is due to hyperscalers; carbon intensity decreased from 366.9 gCO_2e/kWh in 2019 to 312.7 gCO_2e/kWh in 2024. The report concludes that carbon emissions by datacenters increased by +12.1% between 2019 and 2024.

Following the terminology and methodology used in this paper, the above ESG analysis reports that datacenter energy consumption increases at a CAGR of +11.7% while (location-based) carbon intensity decreases at a CAGR of -3.1% — in line with the results reported in this paper. What the datacenter ESG analysis by Structure Research does not provide though is an analysis in the broader environmental context offered in this paper. Using the Kaya identity, this paper reveals that the energy consumption by hyperscalers increases faster than their gross revenue, making the datacenter industry increasingly energy-revenue intensive as opposed to the global trend towards energy-efficient operation.

[2]Carbon intensity of electricity production is decreasing at a CAGR of -1.4%, while carbon intensity of global energy production is decreasing at a CAGR of -0.7% since 2019 as previously reported in Section II.

VI. Conclusion

Datacenters are responsible for a significant and rising fraction of today's electricity consumption and consequently GHG emissions. By looking through the lens of the Kaya identity, this paper argues that the Big Tech industry goes against the world's trend towards reduced energy intensity: Big Tech's energy-revenue intensity increases by +9.6% per year while the world's energy-GDP intensity decreases by -1% per year. While procuring carbon-free energy reduces Big Tech's own carbon footprint, this does not lead to a global reduction in emissions because of the zero-sum game, i.e., green energy purchased by Big Tech cannot be purchased by others. This argument posits that market-based greenhouse gas (GHG) reporting is misleading, advocating instead for reporting location-based emissions. It contends that Big Tech's environmental footprint is demonstrably increasing due to its rising energy intensity. Hopefully this insight will encourage researchers and engineers to improve the energy and carbon efficiency of hyperscale datacenters moving forward.

Acknowledgements

This work is supported in part by the Research Foundation Flanders (FWO) grants No. G096225N and G031826N.

References

[1] Lifecycle carbon intensity of electricity generation – with major processing by Our World in Data. "Lifecycle carbon intensity of electricity generation – Ember" [dataset]. Ember, "Yearly Electricity Data Europe"; Ember, "Yearly Electricity Data" [original data]., year = 2026, url = https://ourworldindata.org/grapher/carbon-intensity-electricity.

[2] Microsoft 2020 environmental sustainability report, 2020. URL https://www.microsoft.com/en-us/corporate-responsibility/reports-hub#sustainability.

[3] Apple 2023 environmental progress report, 2023. URL https://www.apple.com/environment/pdf/Apple_Environmental_Progress_Report_2023.pdf.

[4] Apple 2024 environmental progress report, 2024. URL https://www.apple.com/environment/pdf/Apple_Environmental_Progress_Report_2024.pdf.

[5] Google environmental report, 2024. URL https://www.gstatic.com/gumdrop/sustainability/google-2024-environmental-report.pdf.

[6] Data centres metered electricity consumption 2023 – Central Statistics Office, Ireland, July 2024. URL https://www.cso.ie/en/releasesandpublications/ep/p-dcmec/datacentresmeteredelectricityconsumption2023/.

[7] Meta 2024 sustainability report, 2024. URL https://sustainability.atmeta.com/wp-content/uploads/2024/08/Meta-2024-Sustainability-Report.pdf.

[8] Accelerating the addition of carbon-free energy: An update on progress, Sept. 2024. URL https://www.microsoft.com/en-us/microsoft-cloud/blog/2024/09/20/accelerating-the-addition-of-carbon-free-energy-an-update-on-progress/.

[9] International Energy Agency (IEA): Energy and AI, 2025. URL https://www.iea.org/reports/energy-and-ai.

[10] Apple 2025 environmental progress report, 2025. URL https://www.apple.com/environment/pdf/Apple_Environmental_Progress_Report_2025.pdf.

[11] Google environmental report, 2025. URL https://www.gstatic.com/gumdrop/sustainability/google-2025-environmental-report.pdf.

[12] Global carbon budget – with major processing by Our World in Data. “CO2 emissions” [dataset]. Global Carbon Project, “Global Carbon Budget v15” [original data], 2025. URL https://ourworldindata.org/grapher/kaya-identity-co2.

[13] Microsoft 2025 environmental sustainability report – data fact sheet, 2025. URL https://cdn-dynmedia-1.microsoft.com/is/content/microsoftcorp/microsoft/msc/documents/presentations/CSR/2025-Microsoft-Environmental-Data-Fact-Sheet-PDF.pdf.

[14] Macrotrends: Amazon revenue 2012-2025 — AMZN, Jan. 2026. URL https://www.macrotrends.net/stocks/charts/AMZN/amazon/revenue.

[15] Macrotrends: Apple revenue 2012-2025 — AAPL, Jan. 2026. URL https://www.macrotrends.net/stocks/charts/AAPL/apple/revenue.

[16] Macrotrends: Alphabet revenue 2012-2025 — GOOG, Jan. 2026. URL https://www.macrotrends.net/stocks/charts/GOOG/alphabet/revenue.

[17] Macrotrends: Meta platforms revenue 2012-2025 — META, Jan. 2026. URL https://www.macrotrends.net/stocks/charts/META/meta-platforms/revenue.

[18] Macrotrends: Microsoft revenue 2012-2025 — MSFT, Jan. 2026. URL https://www.macrotrends.net/stocks/charts/MSFT/microsoft/revenue.

[19] Meta announces nuclear energy projects, unlocking up to 6.6 GW to power American leadership in AI innovation, Jan. 2026. URL https://about.fb.com/news/2026/01/meta-nuclear-energy-projects-power-american-ai-leadership/.

[20] DCD news - moratorium, 2026. URL https://www.datacenterdynamics.com/en/news/?tag=moratorium.

[21] M. Crippa, D. Guizzardi, F. Pagani, M. Banja, M. Muntean, E. Schaaf, F. Monforti-Ferrario, W. Becker, R. Quadrelli, A. Risquez Martin, P. Taghavi-Moharamli, J. Köykkä, G. Grassi, S. Rossi, J. Melo, D. Oom, A. Branco, J. San-Miguel, G. Manca, E. Pisoni, E. Vignati, and F. Pekar. GHG emissions of all world countries, 2024. URL https://op.europa.eu/en/publication-detail/-/publication/dd80d863-6a63-11ef-a8ba-01aa75ed71a1/language-en/.

[22] L. Eeckhout. The sustainability gap for computing: Quo vadis? *Communications of the ACM*, 68(3):70–79, 2025.

[23] C. Freitag, M. Berbers-Lee, K. Widdicks, B. Knowles, G. S. Blair, and A. Friday. The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations. *Patterns*, 2(9), 2021.

[24] Y. Kaya and K. Yokoburi. *Environment, energy, and economy : strategies for sustainability*. United Nations University Press, 1997. ISBN 9280809113.

[25] I. Schneider, H. Xu, S. Benecke, D. A. Patterson, K. Huang, P. Ranganathan, and C. Elsworth. An introduction to life-cycle emissions of artificial intelligence hardware. *IEEE Micro*, 45(5):9–19, 2025.

[26] A. Shehabi, S. J. Smith, A. Hubbard, A. Newkirk, N. Lei, M. A. Siddik, B. Holecek, J. G. Koomey, E. R. Masanet, and D. A. Sartor. 2024 United States data center energy usage report – US Department of Energy – Lawrence Berkeley National Laboratory, Dec. 2024. URL https://escholarship.org/uc/item/32d6m0d1.

[27] J. Tan and V. Kong. ESG report series. 2025 state of environmental impact: Data centre providers & hyperscale platforms. Structure Research, Feb. 2025. URL https://www.infrastructuresummit.io/esg-report.