In Hot Water: Challenges with Measuring Data Center Water Usage

MICHAEL BRAND
SABRINA TO
UNIVERSITY OF CALIFORNIA, BERKELEY

With the development of emerging technologies, data centers have emerged as critical yet resource-intensive facilities. While much scholarship has focused on their growing energy demands, far less attention has been given to their water consumption—despite its escalating scale and concentration in water-stressed regions. This article examines the challenges of measuring data center water usage by focusing on Water Usage Effectiveness (WUE), the industry's primary water efficiency metric. We trace the development of WUE, evaluate its widespread use in industry reporting, and identify three major limitations: its dependence on IT energy consumption as a denominator, its seasonal variability, and its failure to account for water type and geographic context. We argue that while WUE provides value for internal benchmarking, its application as a regulatory instrument risks underestimating true water impacts and misdirecting policy. We conclude that policymakers should adopt a set of holistic water usage metrics to effectively analyze and reduce the impact of data center water demands.

Keywords: Data Centers, Sustainability metrics, Energy-Water nexus, Water, Environmental policy, Technology policy, Science & technology studies
DOI: https://doi.org/10.60690/bqpqk141

Introduction

As emerging technologies like Artificial Intelligence, large language models, and 5G continue to expand, so do the digital infrastructures they rely upon. The largest of these are data centers, which are the infrastructures responsible for storing and computing all of our data. While these facilities are the backbone of all social and economic life, they historically have remained invisible to the public eye, and so too has their environmental impact. Over the past decade both academic researchers and popular news outlets have documented the massive energy demands of these infrastructures. To document these impacts, researchers are now contributing to the emergence of a new interdisciplinary field known as Critical Data Center Studies [1, 2]. As the material nature of the cloud continues to be unveiled, much of the research still focuses on their increasingly large power demand [3, 4, 5]. In comparison, much fewer examine data center water demands.

Data centers are extremely water-intensive. For instance, Meta totaled 3.1 billion liters of water in 2023 across all its data centers and offices [6]. For 2024, Microsoft reported using a total of 5.8 billion liters of water [7]. In the same year, Apple reported 6.8 billion liters employed, with 87% being freshwater [8]. Similarly, Google reported 30.7 billion liters of water used, with 27.3 billion liters (~88%) originating from freshwater sources [9]. In total, the International Energy Agency estimates that "global water consumption for data centres is currently around 560 billion litres per year, and this could rise to around 1200 billion litres per year in 2030" [10]. But most of these estimates only account for the water that data centers use for cooling their servers. This omits the massive amount of water that data centers use in the construction phases of their projects and the even larger amount of water used for cooling the energy sources they depend on. In fact, the Lawrence Berkeley National Laboratory estimated that in 2023, the indirect water footprint of data centers in the United States was nearly 800 billion liters [11]. This is even more problematic considering that, in the United States, two-thirds of data center developments have been placed in highly water-stressed regions since 2022 [12].

Academics have begun to examine data center water usage. Some have shown the physical entanglements between data centers and their water usage in drought-ridden communities [13, 14]. Others have advocated for more transparency and reporting from big technology companies on their water usage [15, 16]. And a few are examining potential regulations for data center water usage in the context of emerging technologies [17]. Given this emerging focus, it is important to consider the metrics used to understand data center water usage. While there is a wide variety of research that critiques data center energy efficiency metrics, there is much less examining data center water metrics. In this article, we analyze Water Usage Effectiveness (WUE), which is the primary sustainability metric that policymakers are considering to use for data center water usage regulation. First, we define WUE and track its development since being established in 2011. Second, we examine some of the ways in which WUE can be manipulated, making it difficult to use as a policy tool. Finally, we look to show that a holistic and multi-dimensional understanding of these impacts is essential to improving measurements for them.

Water Usage Effectiveness

The most common metric that is used in the data center industry for water efficiency measurement is WUE. The definition of WUE (per ISO/IEC 30134-9:2022) is the ratio of the data center water consumption (in liters) to the sum of energy consumed by IT equipment (in kilowatt-hours) and is measured in liters over kilowatt-hours (L/kWh). A lower value indicates greater water efficiency; an ideal value close to 0 would indicate negligible or no water use. The metric was first established by the Green Grid in 2011, where they noted the importance of having both a WUE score and a WUE score that included both facility-based water usage and water used in the production of energy for the data center (WUE source) [18]. However, WUE source calculations are complex and highly vary based on the source of electricity, resulting in most users only tracking the efficiency of their facility-based water usage [11]. The WUE metric joined two other Green Grid data center metrics, Power Usage Effective (PUE) and Carbon Usage Effectiveness (CUE), to form the xUE family of metrics. It was designed to equip data center operators with the tools to produce a quick sustainability assessment for their facilities [19, 20]. Despite being in the same suite of metrics, PUE is utilized and reported far more than CUE or WUE. This has resulted in most of the research surrounding sustainability metrics for data centers to focus on PUE instead of other sustainability metrics [21, 22, 23]. However, some companies do report WUE and are using it to showcase sustainability improvements.

While WUE is a less commonly reported metric than PUE, it is still used widely throughout the data center industry as the primary water efficiency metric. A study by Lawrence Berkeley National Laboratory estimated that the average WUE of data centers in the United States for 2023 was 0.36 L/kWh [11]. Many large technology companies claim to be much more efficient. Microsoft, for instance, claims that they have improved WUE by over 80% from the early 2000s to 2023 [24]. In 2025, they reported an annual average WUE of 0.30 L/kWh, noting that direct to-chip liquid cooling was a major driver of their progress [7]. Amazon reported an average WUE of 0.15 L/kWh in 2024, a 17% improvement from the previous year [25]. Meta reported their WUE of 0.18 L/kWh in 2023, noting their progress from using air-cooling methods [6]. While it can be tempting to compare these figures, it is important to note that WUE varies widely by region. For instance, temperature fluctuates and more water is required for cooling in warmer regions, leading to a higher WUE. In addition, data center size has similar effects, where economies of scale cause larger data centers to typically have a smaller WUE [11].

Given the prominence of the metric, governments are looking to use WUE to regulate data center water usage. The European Union's Code of Conduct for Energy Efficiency in Data Centres now mandates the reporting of Water Usage Effectiveness for data centers [26]. The newly implemented German Energy Efficiency Act requires this as well [27]. Singapore's Green Data Centre Roadmap also calls for the reduction of WUE to 2 L/kWh over the next decade, after the country's median WUE for large data centers was 2.2 L/kWh in 2021 [28]. China is also in the process of establishing data center water usage benchmarks using WUE, though it hasn't chosen an exact number [29]. While these policies are well-intentioned, they may fall short in reducing data center water consumption given some of the pitfalls of WUE.

A Watered-Downed Metric

While WUE is a standardized metric, it was primarily designed as a tool for internal benchmarking. As a result, it can be easily manipulated when used as a metric for public policies. Concerns have been widely documented regarding the data center industry's circumvention of sustainability metrics like the energy efficiency metric PUE [30, 31, 32]. However, critiques of WUE in the context of policy-making have not been widely discussed. There are three primary challenges with WUE that may water down the regulations that use it.

First, the denominator of WUE is the sum of energy consumed by IT equipment. This means that any data center operators who are solely focused on reducing WUE may potentially stop reducing (or even look to increase) their energy consumption, as higher energy usage would lower WUE scores. This becomes more concerning in the context of emerging cooling technologies. For example, hyperscale data centers turning to immersion cooling will dramatically reduce their water usage, while potentially increasing energy usage [33]. Despite the WUE showing an improvement for direct water usage, in reality, the same amount continues to be used. The resulting effects on the environment are actually worse because of power usage increases, which in turn also increases indirect water usage.

Second, WUE can change with the seasons. Given that much of direct data center water consumption comes from cooling, data centers have a smaller WUE during colder months and a larger WUE during hotter ones. Some data centers even use different cooling techniques during different seasons [34]. One study of a medium-sized data center in Maryland found that WUE varied from 1.3 L/kWh to 2.5 L/kWh over the course of the year [35]. Depending on how regulators monitor WUE, one could imagine that companies only measure their WUE during a cold month and report that score, which isn't truly reflective of the data center's water efficiency. As such, operations could exceed the regulations placed by policies without consequence, which ultimately makes legislation ineffective.

Third, WUE does not account for where the water is sourced. While some data centers are looking to use recycled water or non-potable water to cool their data centers, most still use freshwater [15, 36, 37]. Additionally, many data centers are placed in water-stressed areas [12, 16, 38]. While it's better for data centers to draw from non-freshwater resources or from areas with an abundance of water, WUE does not reflect either of these important factors. This is important for policymakers, as most policies are meant to cut down on freshwater consumption, especially excessive amounts in drought-ridden communities. If WUE is the only metric used for doing so, policymakers won't be effective at limiting these developments or supporting innovations that truly protect their communities.

In addition to all of these challenges, there are concerns that policymakers may misinterpret what WUE truly measures. WUE does not measure the total water consumption of data centers, nor the efficiency of water consumed by producing the vast amounts of energy these facilities require (unless they are using the WUE source metric), nor any of the water used in the supply chain. Mistaking WUE as a measurement that examines water use instead of water efficiency may leave policymakers believing a data center isn't draining their water resources because of a low WUE, while in reality, these facilities are using millions of gallons of water per year.

Glass Half-Full or Half-Empty?

As policymakers look to limit the massive environmental impacts of data centers, they cannot afford to ignore their water usage. When considering the methods for regulating data center water usage, they must be careful in picking which metrics to focus on. While WUE is great for internal usage by data centers to compare the water efficiency of different cooling systems, it was never designed to be used to compare data centers, measure their water usage, or to inform regulation.

This doesn't mean that WUE should never be used by policymakers. It is still a widely accepted metric for measuring water efficiency, and has the advantage of being commonly understood and implemented by the data center industry. Governments mandating the reporting of WUE are gaining essential data that can help guide them to create stronger policies in the future. However, policymakers looking to limit the impact of data centers' water usage on their communities should use WUE in conjunction with other metrics designed to measure total data center water usage, including WUE site metrics that account for water type (fresh vs. non-potable) and source location (water-stressed or water-abundant). By using a more holistic suite of metrics, policymakers will have a stronger chance to curb the impacts of data centers on their communities' water supply.

While it can be tempting to see the large water demands of data centers as a glass half empty, it is not out of the question to see the glass as half full. Data center companies are increasingly reporting their water usage, implementing emerging technologies or restoration projects to reduce them, and policymakers are looking for ways to protect their communities from water stress. Further research into data center metrics, whether it be methods the data center industry is currently using or novel ones (perhaps accounting for water strain), may help create a digital future where the glass is no longer half-full, but overflowing.

References

[1] Edwards D., Cooper ZGT, and Hogan M. "The making of critical data center studies," *Convergence*, *31*(2), 429-446, 2024. Available at: https://doi.org/10.1177/13548565231224157. [Accessed Aug. 30, 2025].

[2] Hogan, M. "'Environmental media' in the cloud: The making of critical data center art," *New Media & Society*, *25*(2), 384-404, 2023. Available at: https://doi.org/10.1177/14614448221149942**.** [Accessed Aug. 30, 2025].

[3] Brodie, P. "Climate extraction and supply chains of data." *Media, Culture & Society*, *42*(7-8), 1095-1114, 2020. Available at: https://doi.org/10.1177/0163443720904601. [Accessed Aug. 30, 2025].

[4] Libertson F, Velkova J, and Palm J. "Data-center infrastructure and energy gentrification: perspectives from Sweden. *Sustainability: Science, Practice and Policy*, *17*(1), 152–161, 2021. Available at: https://doi.org/10.1080/15487733.2021.1901428. [Accessed Aug. 30, 2025].

[5] Sailing, CA, and Maguire, J. "Industrial Excess: Data Storage, Energy and Utility Planning Before, During and After Digital Industrialisation." *Engaging Science Technology & Society, 10*(3), 90-119, 2024. Available at: https://doi.org/10.17351/ests2023.1943. [Accessed Aug. 30, 2025].

[6] R. Peterson, "2024 Sustainability Report," *Meta Platforms, Inc.*, 2024. Available at: https://sustainability.atmeta.com/wp-content/uploads/2024/08/Meta-2024-Sustainability-Report.pdf. [Accessed Aug. 30, 2025].

[7] Microsoft Corporation Inc., "Environmental Sustainability Report 2025," 2025. Available at: https://www.microsoft.com/en-us/corporate-responsibility/sustainability/report/. [Accessed Aug. 30, 2025].

[8] Apple Inc., "Environmental Progress Report", 2025. Avaliable at: https://www.apple.com/environment/pdf/Apple_Environmental_Progress_Report_2025.pdf. [Accessed Aug. 30, 2025].

[9] Google LLC, "Environmental Report," 2025. Available at: https://sustainability.google/google-2025-environmental-report/. [Accessed Aug. 30, 2025].

[10] International Energy Agency, "World Energy Outlook Special Report," *International Energy Agency*, 2025. Available: https://iea.blob.core.windows.net/assets/601eaec9-ba91-4623-819b-4ded331ec9e8/EnergyandAI.pdf. [Accessed Aug. 30, 2025]

[11] Shehabi A, Smith S J, Hubbard A, et al., "2024 United States Data Center Energy Usage Report," *Lawrence Berkeley National Laboratory*, 2024. https://eta-publications.lbl.gov/sites/default/files/2024-12/lbnl-2024-united-states-data-center-energy-usage-report.pdf. [Accessed Aug. 30, 2025]

[12] Nicoletti L, Ma M, and Bass D, "AI is Draining Water from Areas that Need it Most," *Bloomberg*, May 2025. Available: https://www.bloomberg.com/graphics/2025-ai-impacts-data-centers-water-data [Accessed Aug. 30, 2025].

[13] Hogan M, "Data flows and water woes: The Utah Data Center," *Big Data & Society*, 2015. Available: Sage Publishing, https://journals.sagepub.com/doi/pdf/10.1177/2053951715592429. [Accessed Aug. 30, 2025].

[14] Valdivia A, "The *supply chain capitalism of AI*: a call to (re)think algorithmic harms and resistance through environmental lens," *Information, Communication & Society*, 2024. Available: Taylor & Francis Online, https://www.tandfonline.com/doi/full/10.1080/1369118X.2024.2420021#abstract. [Accessed Aug. 30, 2025].

[15] Li P, Yang J, Islam M A, et al. "Making AI Less "Thirsty": Uncovering and Addressing the Secret Water Footprint of AI Models," *arXiv*, 2025. Available: https://arxiv.org/abs/2304.03271. [Accessed Aug. 30, 2025].

[16] Mytton D, "Data centre water consumption," *npj clean water*, 2021. Available: Nature Portfolio, https://www.nature.com/articles/s41545-021-00101-w. [Accessed Aug. 30, 2025].

[17] Garcia M, "AI Uses How Much Water? Navigating Regulation Of AI Data Centers' Water Footprint Post-Watershed Loper Bright Decision," 2024. Available: *Social Science Research Network*,

https://papers.ssrn.com/sol3/papers.cfm?abstract_id=5064473. [Accessed Aug. 30, 2025].

[18] Patterson M, Azevedo D, Belady C, et al., "Water Usage Effectiveness (WUE™): A Green Grid Data Center Sustainability Metric," White Paper #35, 2011. Available: The Green Grid, https://airatwork.com/wp-content/uploads/The-Green-Grid-White-Paper-35-WUE-Usage-Guidelines.pdf. [Accessed Aug. 30, 2025].

[19] Belady C, Azevedo D, Patterson M et al., "Carbon Usage Effectiveness (CUE): A Green Grid Data Center Sustainability Metric," White Paper #32, 2010. Available: The Green Grid, https://airatwork.com/wp-content/uploads/The-Green-Grid-White-Paper-32-CUE-Usage-Guidelines.pdf. [Accessed Aug. 31, 2025].

[20] Belady C, Azevedo D, Patterson M et al., "Carbon Usage Effectiveness (CUE): A Green Grid Data Center Sustainability Metric," White Paper #32, 2010. Available: The Green Grid, https://airatwork.com/wp-content/uploads/The-Green-Grid-White-Paper-32-CUE-Usage-Guidelines.pdf. [Accessed Aug. 31, 2025].

[21] Gandhi, A, Lee D, Liu Z, et al. "Metrics for sustainability in data centers." *ACM SIGENERGY Energy Informatics Review*, *3*(3), 40–46, 2023. Available at: https://doi.org/10.1145/3630614.3630622. [Accessed Aug. 31, 2025].

[22] Levy M, and Raniv D, "An overview of data center metrics and a novel approach for a new family of metrics." *Advances in Science, Technology and Engineering Systems Journal 3*(2), 238-251, 2018. Available at: https://dx.doi.org/10.25046/aj030228. [Accessed Aug. 31, 2025].

[23] Shao X, Zhang Z, Song P, et al., A review of energy efficiency evaluation metrics for data centers. *Energy & Buildings, 271,* 2022. Available at: https://doi.org/10.1016/j.enbuild.2022.112308. [Accessed Aug. 31, 2025].

[24] Walsh N, "Sustainable by design: Transforming datacenter water efficiency," *The Microsoft Cloud*. Available: https://www.microsoft.com/en-us/microsoft-cloud/blog/2024/07/25/sustainable-by-design-transforming-datacenter-water-efficiency/?msockid=10cb6adad5056c8305847878d4b66d36. [Accessed Aug. 31, 2025].

[25] Amazon.com, Inc., "2024 Amazon Sustainability Report," 2025. Available at: https://sustainability.aboutamazon.com/2024-amazon-sustainability-report.pdf. [Accessed Aug. 31, 2025].

[26] Directive (EU) 2023/1791 Of The European Parliament And Of The Council, 2023. Full text available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32023L1791. [Accessed Aug. 31, 2025]

[27] Law to Increase Energy Efficiency in Germany (Energy Efficiency Act), 2023. Full text available at: https://www.gesetze-im-internet.de/enefg/BJNR1350B0023.html. [Accessed Aug. 31, 2025].

[28] Infocomm Media Development Authority, "Driving a Greener Digital Future," *Singapore's Green Data Centre Roadmap*, 2024. Available: Infocomm Media Development Authority, https://www.imda.gov.sg/-/media/imda/files/how-we-can-help/green-dc-roadmap/green-dc-roadmap.pdf. [Accessed Aug. 31, 2025].

[29] Jiang F, Duan C, and Chen B. "Facility-level energy-driven water footprint and scarcity implications of Chinese data centers: a bottom-up analysis and scenario-based projection," *Applied Energy*, vol. 399, 2025. Available at: ScienceDirect, https://www.sciencedirect.com/science/article/abs/pii/S0306261925012528#bb0155. [Accessed Aug. 31, 2025].

[30] Horner N, and Azevedo I, "Power usage effectiveness in data centers: overloaded and underachieving," *The Electricity Journal, 29*(4), 61-69, 2016. Available at: https://doi.org/10.1016/j.tej.2016.04.011. [Accessed Aug. 31, 2025].

[31] Brady G, Kapur N, Summers J L, et al., "A case study and critical assessment in calculating power usage effectiveness for a data centre," *Energy Conversion & Management*, (76), 155-161, 2013. Available at: https://doi.org/10.1016/j.enconman.2013.07.035. [Accessed Aug. 31, 2025].

[32] Zakarya M, "Energy, performance and cost efficient datacenters: A survey," *Renewable & Sustainable Energy Reviews, 94,* 363-385, 2018. Available at: https://doi.org/10.1016/j.rser.2018.06.005. [Accessed Aug. 31, 2025].

[33] Rosen N, "Liquid cooling tech represents the data center of tomorrow" *Data Center Dynamics*, 17 December 2024. Available at: https://www.datacenterdynamics.com/en/opinions/liquid-cooling-tech-represents-the-data-center-of-tomorrow/. [Accessed Aug. 31, 2025].

[34] Higgins A, "What is Water Usage Effectiveness (WUE) in data centers?" *Equinix*, 13 November, 2024. Available at: https://blog.equinix.com/blog/2024/11/13/what-is-water-usage-effectiveness-wue-in-data-centers/. [Accessed Aug. 31, 2025].

[35] Lei N and Masanet E, "Climate- and technology-specific PUE and WUE estimations for U.S. data centers using a hybrid statistical and thermodynamics-based approach," *Resources, Conservation and Recycling*, (182), 2022. Available at: https://www.sciencedirect.com/science/article/pii/S0921344922001719#bib0071. [Accessed Aug. 31, 2025].

[36] Swinhoe D, "AWS using reclaimed wastewater for data center cooling at 20 locations," *Data Center Dynamics*, 23 November, 2023. Available at: https://www.datacenterdynamics.com/en/news/aws-using-reclaimed-wastewater-for-data-center-cooling-at-20-locations/. [Accessed Aug. 31, 2025].

[37] Setmajer A, "How data centers can use alternative water sources," *Equinix*, 20 March, 2025. Available at: https://blog.equinix.com/blog/2025/03/20/how-data-centers-can-use-alternative-water-sources/. [Accessed Aug. 31, 2025].

[38] Siddik MAB, Shehabi A, and Marston L, "The environmental footprint of data centers in the United States," *Environmental Research Letters*, 16, 2021. Available at: https://iopscience.iop.org/article/10.1088/1748-9326/abfba1. [Accessed Aug. 31, 2025].