Assessment of water consumption and cooling efficiency specific to AI Data Centers

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Abstract. Given the rapid expansion of artificial intelligence, significant environmental pressure is being applied and it needs to be recognized and appropriately managed. While there are various ways in which the environment is being influenced, water requirements can be a significant downside particularly in regions that face water scarcity. Data centers are nothing new, however, high-density GPU clusters can generate massive amounts of heat which in turn intensify the cooling requirements. This paper evaluates different cooling systems and their respective efficiency as well as water requirements. Common methods of air cooling are becoming inadequate for the cooling process required. As such, liquid cooling is bound to become a staple solution for AI data centers. Environmental assessment methods such as Water Usage Efffectiveness and Power Usage Effectiveness provide great insight when it comes to operational efficiency, but they are not a contextual sustainability metric. Life Cycle Assesments should be used as a complementary method in evaluating environmental impact.

Keywords: Environmental assessment, cooling technology, water management, sustainable computing.

Introduction. The ongoing rush for artificial intelligence advancement raises a natural question: What does it mean for our environment? To be concise, the answer is simply „it depends”. As Hlabisa (2025) points out, artificial intelligence can be as beneficial as it is harmful from an ecological standpoint. According to Patel et al., (2025) there is an expected increase of 200-300 billion gallons of water by 2030 in the US, as a response to AI expansion requirements. Comparatively, the global consumption was of 150 billion gallons in 2023 (IEA, 2025). Although water can be treated and recycled, the speed of the infrastructural growth raises concerns about whether or not current solutions can guarantee the sustainability of this expansion. Some regulatory responses reinforce this concern, such as the Artificial Intelligence Data Center Moratorium Act (2025-2026).

Methods. This assessment reviews and compares literature focused on cooling systems utilized in data centers and their different particularities. For better environmental context, it analyzes Power Usage Effectiveness (PUE), Water Usage Effectiveness (WUE) and life cycle assessment (LCA).

Objective. The paper aims to provide an overview of different approaches to thermal regulation and their efficiency, while correlating them with their specific water requirements. A secondary objective is to reinforce the necessity of LCA alongside WUE and PUE reports in determining the environmental impact associated with AI DC’s.

Water consumption in AI data centers. There are two main categories of water consumption: direct and indirect. Direct usage represents the water utilized in the cooling process while indirect usage refers to water utilized in the production of electricity required to power the center (Siddik et al., 2021; Mytton, 2021; Gniba et al., 2024).

Potable water usage. In the United States a lot of hyperscale data centers draw water from public water systems (Han et al., 2026). This means that water destined for population is being removed from the system, raising concerns in regions that battle water scarcity. As Figure 1 suggests, in the case of potable water usage, water treatment can be considered as part of the data center consumption economy. Minimizing the potable water intake by establishing a boundry between DC's and population resource can reduce additional pressure exerted on water availability.

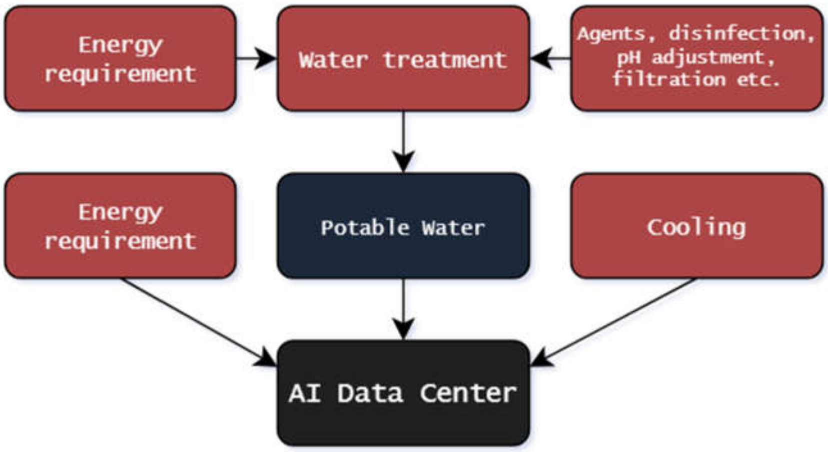

Figure 1. Addition of water treatment requirements to the AI data center consumption economy in the case of potable water usage.

Cooling systems. Traditionally when it comes to data centers, a rack would generally utilize 7 kW (Zhang et al., 2022). DC's are greatly exceeding this energy requirement. GPU clusters are reaching upwards of 350kW per cabinet (Li & Li, 2025). Given that these facilities are permanently operating, thereby constantly generating heat, one of the determining factors for environmental sustainability is represented by thermal management. Table 1 showcases different methods of cooling and their respective characteristics, outlying particularities in terms of efficiency and consumption.

Computer room air conditioning. Computer room air conditioning (CRAC) is commonly used for conventional data centers. Cold air is generated and sent from underneath either in the entire room or to each rack in particular. The cold air absorbs heat dissipated by the servers, and is afterwards discharged into the CRAC unit to be cooled by water (Xu et al., 2023). Given the increase of thermal generation that comes with hardware advancement specific to AI DC's, air no longer suited to provide an efficient cooling solution (Azarifar et al., 2024).

Evaporative cooling. This technological approach utilizes the process evaporation to cool air: as water evaporates the heat is absorbed. It's efficiency depends on ambient air and humidity levels, in humid environment the effectiveness diminishes; additionally, the system requires a continuous water supply (Chang et al., 2024). In comparison to air-cooling systems, Hybrid evaporative cooling can have much low power consumption. (Karimi et al., 2022). In terms of water requirements it is one of the most intensive solutions utilized in digital infrastructure (Natarajan, 2025).

Cold plate liquid cooling. This method implies the attachment of plates (copper is commonly used) directly on the hardware's heat focal points, such as CPU's or GPU's. The plates contain channels through which a coolant is ran, absorbing the heat and in turn maintaining the physical component at a lower temperature. Such an approach was utilized to successfully reduce cooling energy required by 90% when compared to traditional air cooled data centers (Chainer et al., 2017). Another benefit of liquid cooling is the fact that water used as coolant can have much higher temperatures, reducing the cost associated with cooling infrastructure (Coles & Greenberg, 2014).

Immersion Cooling. With this method the unit is submerged into a thermally and nonelectrically conductive liquid (dielectric fluid), as a result it is permanently in contact with the entirety of the equipment (Hnayno et al., 2023). There are two variants: single and two-phase immersion. In single phase cooling the coolant remains in a liquid state, it absorbs heat, gets transferred to a heat exchanger and then gets recirculated after cooling. In two-phase immersion the liquid simply boils after heat absorbtion, is then condensed and recirculated through gravity after contacting a cooled surface. As pointed out by Zhou et al., (2024) both methods can reduce water requirements due to the possibility of utilizing adiabatic dry coolers instead of cooling towers. In the case of two-phase cooling, specialised fluid can be lost due to the process of evaporation.

Free Cooling. These types of systems incorporate natural resources such as cold air or water in order to greatly reduce energy costs. The principle is simple, if the temperature outside is lower than indoors, the air or water can be drawn and utilized without needing to expend resources for cooling. This type of approach is limited by natural regional climate factors, as well as environmental concerns in the case of water (Xu et al., 2023).

Seawater Cooling. Another alternative to freshwater is represented by sea water. Google has shown the possibility of pumping cold sea water within the facility as a way to reduce potable water usage in the heat exchanging process with Google Hamina reportedly utilizing this method since 2011 (Mytton, 2021).

Table 1

Characteristics of cooling solutions for AI DC

Cooling method	*Advantage*	*Limitation*	*Freshwater consumption*
Computer Room Air Conditioning (CRAC)	Consolidated technology	Limited cooling efficiency	Moderate
Evaporative	Energy efficient in dry climates	Very low efficiency in humid climates	Very High
Cold Plate Liquid	Reduced cooling energy demand	Design complexity	Moderate to Low
Single-Phase Immersion	High thermal efficiency	Specialized fluids; design complexity	Low
Two-Phase Immersion	Extremely high thermal efficiency	Specialized fluids; design complexity	Low
Free	Natural input	Climate dependant	None or Low
Seawater	Negates freshwater usage	Geographic limitations	None

Sustainability metrics. The main leading concepts that are significant for a DC from a sustainability perspective revolve around the efficiency of the operation. Power Usage Effectiveness (PUE) and Water Usage Effectiveness (WUE) are methods utilized for the purpose of evaluation. Life Cycle Assessment (LCA) is an additional tool used that can provide insight on the environmental footprint generated. Table 2 provides an overview.

Power Usage Effectiveness. PUE is a metric commonly used the DC industry that evaluates energy efficiency. It represents a ratio between total energy consumption and energy that is strictly utilized to power IT equipment (Uanov & Begimbetova, 2022; Kim et al., 2024). A ratio of 1:1 would indicate perfect efficiency; although this ratio is nearly impossible to achieve, companies strive to get as close as possible to it. By separating IT equipment (GPU, server, storage etc.) from equipment by which cooling is achieved we can form an idea of how efficient the facility is in utilizing the energy.

$$PUE = \frac{Total\ Facility\ Energy}{IT\ Equipment\ Energy}$$

Water Usage Effectiveness. Another way of deciding efficiency is provided by utilizing WUE. It is a metric that defines water consumption by evaluating the ratio between annual site water usage and IT equipment energy usage. This method of measurement only includes on-site usage. Water utilized in energy generation is also an important metric. As such, WUEsource is an adaptation ment to more accurately assess efficiency by adding water consumed in energy generation to the on-site usage (Mytton, 2021).

$$WUE = \frac{Annual\ Site\ Water\ Usage}{IT\ Equipment\ Energy}\ ;\ WUEsource = \frac{Annual\ Source\ Energy\ Water\ Use + Annual\ Site\ Water\ Usage}{IT\ Equipment\ Energy}$$

Life Cycle Assessment. LCA is a standardized methodology (ISO, 2006a, 2006b) used to assess environmental impact associated with either a product, system or infrastructure. It provides an overview for each stage and their respective influence, from raw material acquisition to waste management (Curran, 2013). It quantifies and evaluates environmental pressure applied during different lifecycle stages of an activity to the corresponding biotic or abiotic environmental components. Life cycle assesment has proven to be useful in showing the reduction of potable water usage in the case of advanced cooling methods (Alissa et al., 2025). While LCA can indicate through system comparison which of them has less environmental impact, it cannot prove sustainability alone (Hauschild et al., 2017, p.14).

Discussions and Limitations. Imminent growth of AI DC's are bound to further accentuate the pressure on water resources in the case of potable water use.

Cooling systems. Cooling systems such as CRAC cannot sustain the cooling requirement an AI DC has. Evaporative cooling can suffer greatly in the case of humid climate, and requires a large amount of water supply. Liquid cooling seems the most reliable way to move forward, from an environmental perspective. They show the best results in terms of cooling efficiency, as well as water consumption. Immersion cooling technology can be expensive to implement and sustain as a result of specialised liquids. Evaporation of such liquids leads to high maintenance cost. Free cooling and seawater usage are great resource alternatives, but they can only be implemented in certain regions. There is an argument to be made in the case of seawater disposal, however, which is that heated seawater can thermally disrupt ecosystems causing pollution.

Sustainabilty metrics. Sustainability metrics can contribute to overall efficiency, with PUE and WUE giving great operational insight, but they do not paint the full picture. If a specific region is suffering from water scarcity for example, as long as potable water is being used the project will continue to apply environmental pressure no matter how efficiently it is being utilized. LCA is a more suitable environmental evaluation of a DC project, but it does not prove sustainability.

Conclusions. To be able to sustain hyperscale AI DC projects, achieving potable water neutrality is one of the most important aspects. Immersion cooling is the most efficient cooling approach. Further research is required in order to mitigate specialised fluid loss during the process in the case of two-phase immersion, as to lower the cost required for maintenance. Free cooling solutions should be utilized when possible, as they provide a free source of energy. Seawater as a replacement for potable water can be used where the location allows it, however, if disposal is necessary it has to be carefully managed. While LCA is a valuable tool, it cannot prove sustainability. That is to say, LCA is a tool which can indentify what pathway is better for the environment and not the lowest possible impact obtainable. Including regional particularities, such as water supply, should be considered. A method that evaluates what percentage of the total potable water supply of a region is required to operate the AI DC, accompanied by other sustainability metrics, seems more suitable for an environmental impact evaluation.

Authors Contributions. Vlad Chioran contributed to all aspects of the work.

Conflicts of Interest. The author declares that there is no conflict of interest.

Data Availability. The data supporting the findings of this study are available from the author upon reasonable request.

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