
Reclaiming Cooling: Wastewater Reuse as a Strategic Resource for Data Center Water Management

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Abstract— As data center developers turn to arid regions of the US for new projects, water for cooling becomes an ever more pressing concern. Water-driven cooling is one of the most efficient ways to cool data centers, lowering power usage effectiveness (PUE). Cooling towers account for 20 – 30% of water demand at power plants, and the potential substitution of reclaimed municipal wastewater has been projected to save up to 300 million gallons per day of freshwater withdrawals across power plants in Texas [1]. Although the current literature on this substitution is growing, the full environmental cost of using wastewater has not been compared with that of freshwater in a single life cycle assessment that accounts for tertiary-treatment energy, a dual-pipe distribution system, chemical use, and blowdown. This research fills that gap through a comparative life cycle analysis (LCA). This study builds on Akhoundi’s [2] work and uses depth filtration, granular activated carbon (GAC), and chlorination as the primary treatment train, quantifying impacts across three main categories: global warming potential (GWP), cumulative energy demand, and freshwater displacement. Isolating these categories within an impact assessment and sensitivity analysis allows us to identify tradeoffs between energy use, carbon emissions, and water consumption. A wastewater scenario has about twice the GWP of the freshwater case, with treatment energy accounting for roughly 80% of the difference. This research analyzes different treatment trains. Looking at the UF+RO scenario, wastewater energy usage grows to over five times that of freshwater, but is balanced out by improvements in cycles of concentration (COC) that would reduce blowdown and chemical consumption. Running the GWP sensitivity analysis under a fully decarbonized grid scenario shows a significant reduction in carbon-equivalent emissions, with chemical production remaining as the main contributor. A cooling system commissioned today and operated through 2050 would spend the majority of its service life under grid conditions where the GWP penalty of reuse is negligible, while its water savings accrue at full value. While the substitution of reuse water for freshwater is one-to-one, an indirect water penalty of approximately 0.93 L/m³ results from the higher upstream electricity and chemical inputs in the reuse train. This number however, is nearly negligible, accounting for less than 0.1 percent of the direct displacement benefit. Because water treatment falls on the utility, municipal-data-center water partnerships could offer significant benefits that cannot be captured by an operational LCA alone. These findings provide a decision framework for data center developers, utilities, and regulators evaluating reclaimed water infrastructure.

Keywords—Wastewater, cooling towers, data centers, artificial intelligence, water management, global warming potential, water scarcity.

1. LITERATURE REVIEW

This study is at the intersection of three bodies of literature: the water and energy needs of data centers, life cycle assessments of industrial cooling towers, and wastewater reuse in industrial and data center contexts.

1.1. Water and Energy Needs of Data Centers

In 2021, Mytton [3] estimated that training a single large language model can consume hundreds of thousands of liters of water for cooling and that data centers in arid regions can require up to 2.18 liters of water per kWh of server energy. With the expansion of artificial intelligence, the 626 billion liters of water that were consumed by US data centers in 2014 will only increase according to Shehabi

[4]. This concern is compounded as developers turn to hot climate states like Arizona, Nevada, and Texas, causing water availability to become a key bottleneck. As a result, a few data center operators and academics have started evaluating alternative cooling water sources. Both Microsoft and Google have publicly committed to using non-potable and reclaimed water at their data center sites [5] and Equinix has started looking at desalination and reclaimed water as alternatives [6]. In parallel, Alissa et al. are exploring less water intensive alternatives like cold plate/direct to chip, single phase immersion cooling, and two-phase immersion cooling which are significantly more complicated than the traditional cooling tower [7]. Despite the growing interest, none of these studies ran a comparative LCA quantifying the trade-offs between reclaimed water and freshwater for cooling towers across multiple impact categories, and none accounted for the indirect water footprint of the additional treatment energy required for reuse. This is the gap that our study addresses.

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1.2. LCA of Industrial Cooling Towers

Schulze, Thiede, and Herrmann [8] published in 2018 the first cradle-to-grave LCA of industrial cooling towers, providing the methodology and life cycle inventory (LCI) data benchmarks for this study. Using a forced-draft wet cooling tower in Germany as the case study, their study demonstrated that the operational stage accounts for 96% of Global Warming Potential over a 20-year system life, a finding that justifies restricting our system boundary to operations and excluding infrastructure construction and end-of-life. The electricity documented in their LCI (864 MWh over the system lifetime) is consumed primarily by the recirculation pumps that move heated water from production machines to the top of the tower and back, and by the fan motor that forces air through the tower in counterflow to the falling water. They showed that electricity consumption for pump and fan operation is the largest driver of GWP, followed by freshwater demand and wastewater treatment. Their functional unit of 1 kilogram of water from 35 to 28 degrees Celsius provides the basis for the functional unit used in this study.

Wenzel and Radgen [9] extended this foundation in 2023 by comparing energy and environmental assessment methods for a wet-cooling tower in a high-performance data center. Their finding that electricity and water consumption together drive more than 97% of impacts across all examined impact categories confirms that operational flows dominate the environmental profile of wet cooling tower systems. This supports our methodological choice to focus our LCA on the operational phase rather than a comprehensive cradle-to-grave assessment. Thus, we selected the following impact categories: GWP, freshwater depletion, and cumulative energy demand collectively capture the dominant environmental interactions of wet cooling tower systems.

1.3. Wastewater Reuse in Industry

Akhoundi et al. [2] provide the benchmarking data for the reuse scenario in this study. By applying ISO 14040 LCA methodology to 20 different tertiary treatment options, the authors found that energy consumption is the primary driver of environmental impact across all treatment trains. Specifically for cooling tower applications, they identified the UF + RO + Chlorination treatment configuration as the lowest-impact option.

Badruzzaman et al. [10] conducted a pilot study in 2022 of reclaimed municipal water as cooling tower makeup at an oil and gas facility in an arid climate. Their reported 27% reduction in makeup water demand arose from the substitution of reclaimed water for freshwater withdrawal, which directly reduces the demand placed on natural water sources, and the optimization of COC from 2 to 3.5, enabled by the chemical management program implemented for the reclaimed water stream. Their work also documents the complications of reclaimed water reuse, including elevated biohazard risk requiring more aggressive biocide programs, scaling and corrosion challenges arising from the higher total dissolved solids of reclaimed water. These factors are incorporated into our LCI chemical load assumptions.

The study of urban water systems in the Greater

Cincinnati region [11] provides benchmarks for freshwater scenarios. Their analysis of a full municipal water and wastewater system using utility data established that water distribution alone accounts for 51% of system energy consumption, making explicit the environmental cost of conventional freshwater supply that is often omitted from reuse comparisons. Their discussion further confirmed that the electricity mix is the dominant variable affecting all environmental outcomes, a finding that motivates our grid carbon-intensity sensitivity analysis.

2. METHODS

2.1. Scenario Framework and Boundary Conditions

This paper evaluates the environmental impacts of two cooling tower water-supply scenarios using a comparative life-cycle assessment. The analysis compares the use of conventional freshwater (Scenario A) and reclaimed reuse water (Scenario B) as water sources for cooling tower operation, with both cases having an annual makeup water volume of 50,000 m³/yr. This annual makeup water demand of nearly 13.2 million gal/yr, represents a small-to-medium evaporatively cooled data center. The annual makeup water demand of 50,000 m³/yr was contextualized using a representative data center WUE of 1.8 L/kWh, which has been reported as an average value for data center facilities and corresponds to approximately 27.8 GWh/yr of electricity use and an average continuous IT load of ~ 3.2 MW. Larger hyperscale facilities may consume several hundred thousand to millions of cubic meters of water annually. Both scenarios were modeled under equivalent cooling-demand conditions to isolate the environmental differences resulting specifically from water sourcing, treatment requirements, and operational performance.

Scenario A represents conventional freshwater use, where surface or groundwater is withdrawn and subjected to standard conditioning, including softening and baseline biocide treatment. This water is distributed via a single-pipe supply network and used as cooling tower makeup water. Scenario B represents a reuse water system in which reclaimed municipal wastewater, collected from a wastewater treatment plant via different treatment trains. Depth Filter + GAC + Chlorination is distributed via a dual-pipe reclaimed water network and used as cooling tower makeup water. This treatment train was selected based on findings from Akhoundi et al. [2], which identified depth filtration + GAC + chlorination as the lowest impact reuse option at approximately 0.42 kWh/m³ compared to more energy-intensive ultrafiltration and reverse osmosis systems that can exceed 1.85 kWh/m³. Another technology considered is a membrane bioreactor (MBR), which relies on microorganisms suspended in wastewater for treatment. It is highly efficient at removing contaminants such as nitrogen, phosphorus, and bacteria according to the EPA [12]. Additionally, another advanced treatment option is ultrafiltration followed by reverse osmosis (UF + RO). UF removes suspended solids, bacteria, and viruses, while RO removes dissolved contaminants, producing higher-quality reclaimed water than either the Depth Filtration + GAC +

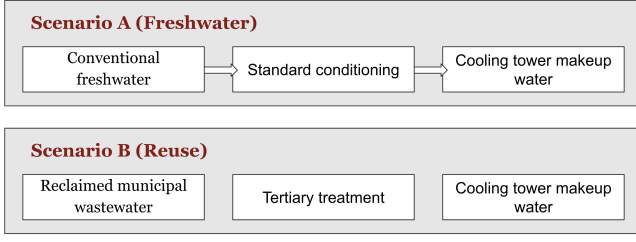


Fig. 1: Comparison of scenarios A and B.

Chlorination treatment train or MBR systems. However, this improved treatment performance comes with substantially higher energy requirements than the other technologies.

The system boundary for both cases includes the major operational processes associated with cooling tower water management. These processes include water sourcing, treatment, pumping and distribution, and cooling tower operation. The assessment considers freshwater withdrawal or reclaimed effluent collection, tertiary treatment for water reuse, conditioning treatment for freshwater, pumping and delivery of water to the cooling tower, electricity consumption during operation, chemical treatment requirements, and cooling tower blowdown management. Infrastructure construction, equipment manufacturing, and end-of-life disposal processes were excluded from the analysis because the study focuses primarily on operational environmental impacts. See more details in *Table S0*, which includes our assumptions for both scenarios.

2.2. Lifecycle Inventory (LCI)

The LCI was developed to quantify the water, chemicals, and energy flows associated with each cooling tower scenario. Inventory data included freshwater consumption, electricity demand from water treatment and pumping, and chemical loads. All data were calculated per cubic meter and include annual estimates.

For Scenario A, compared with reuse water systems, freshwater systems generally operate with lower dissolved solids concentrations, which influences both treatment demand and blowdown behavior during cooling tower operation. For Scenario B, additional tertiary treatment processes were incorporated into the inventory to account for the treatment required before reclaimed water could be used as cooling tower makeup water. The TDS values were chosen to represent realistic cooling-water sources: ~ 200 mg/L for treated freshwater and ~ 800 mg/L for reclaimed municipal wastewater after tertiary treatment. Depth filtration, GAC, and chlorination improve water quality but do not significantly remove dissolved salts, so reclaimed water retains higher TDS concentrations that affect CoC, blowdown, and chemical demand. Because reuse water typically contains higher TDS concentrations than freshwater, the system was also evaluated under different CoC assumptions to examine the relationship between dissolved solids accumulation, blowdown frequency, and overall operational efficiency.

2.3. Impact Assessment

We divided our impact assessment into four main categories: (1) energy intensity measured by kWh/m³, (2) GWP measured by kg-CO₂-eq/m³, (3) freshwater displacement, measured by m³ freshwater avoided per m³ makeup, considering net freshwater consumed and scarcity impact weights, and (4) GWP breakeven, measured by kg-CO₂/kWh.

Energy intensity comprises treatment, pumping, and tower operations. We averaged and approximated the values for both the freshwater and water reuse scenarios (see *Tables S1* and *S2*):

$$E_{\text{total}} = E_{\text{treatment (primary train)}} + E_{\text{chemical dosing}} + E_{\text{pumping (source to tower)}} + E_{\text{tower operations}} \quad (2.1)$$

For the GWP, we consider the energy consumption for treatment, pumping, and tower operations, as well as chemical flows from the LCI. We scale these values by their corresponding GWP factors from our assumptions:

$$\text{GWP}_{\text{scenario}} = \sum E_{\text{type}} \cdot \text{GWP}_{\text{energy}} + D_{\text{antiscalant}} \cdot \text{GWP}_{\text{antiscalant}} + D_{\text{biocide}} \cdot \text{GWP}_{\text{biocide}} + \text{direct treatment process emissions} \quad (2.2)$$

For freshwater displacement, we considered the impact of water scarcity on freshwater consumption.

$$V_{\text{net}} = (V_{\text{evap}} + V_{\text{blow}}) \cdot f_{\text{nat}} \quad (2.3)$$

$$I_{\text{ws}} = V_{\text{net}} \cdot \text{WSF} \quad (2.4)$$

where:

- V_{net} net freshwater consumed [m³_{fw avoided}/m³_{makeup}]
- V_{evap} evaporation loss [m³/m³]
- V_{blow} blowdown volume [m³/m³]
- f_{nat} fraction of makeup water drawn from natural freshwater sources
- I_{ws} water scarcity impact [m³_{world-eq}/m³]
- WSF AWARE 2.0 [13] regionalized water scarcity factor

and also,

$$\text{Displacement} = \Delta V_{\text{fw,nat}} \quad (2.5)$$

$$\text{Score}_{\text{scarcity}} = \Delta I_{\text{ws}} \quad (2.6)$$

where Δ denotes the difference between the freshwater and reclaimed wastewater cooling scenarios.

If the two scenarios have a different total energy intensity, we calculate a GWP breakeven grid intensity:

$$\text{GWP}_{\text{breakeven}} = \frac{\Delta \text{GWP}_{\text{chem}} + \Delta \text{GWP}_{\text{direct}}}{\Delta E_{\text{total}}} \quad (2.7)$$

where:

- ΔGWP_{chem} difference in GWP from chemical dosing
- $\Delta GWP_{\text{direct}}$ difference in GWP from direct treatment process emissions
- ΔE_{total} difference in total energy intensity [kWh/m³]

2.4. Sensitivity Analysis

The main variables in our sensitivity analysis are the electricity grid's carbon intensity (1), treatment train choice (2), and CoC (3).

In our model, the user can modify carbon intensity measured by kg-CO₂/kWh across different scenarios and observe the difference, Δ GWP, in kg-CO₂-eq/m³ between GWP of wastewater and GWP of freshwater. In our model, we approximated the grid carbon intensities of different grid scenarios, including US coal-heavy, US average (EPA eGRID 2023), California (high renewable), France (nuclear-heavy), and 100% renewable energy (see *Table S3* for more details). These calculations are modeled by:

$$\begin{aligned} GWP_{\text{scenario}} = & \text{CI} \cdot \sum E_{\text{type}} \\ & + D_{\text{antiscalant}} \cdot GWP_{\text{antiscalant}} \\ & + D_{\text{biocide}} \cdot GWP_{\text{biocide}} \\ & + \text{direct treatment process emissions} \end{aligned} \quad (2.8)$$

where:

- **CI** grid carbon intensity [kg CO₂-eq/kWh]
- E_{type} energy consumption by type [kWh/m³]
- $D_{\text{antiscalant}}$ antiscalant dosing rate [kg/m³]
- D_{biocide} biocide dosing rate [kg/m³]

The model allows the user to select a water treatment train. Three scenarios of increasing water quality and energy intensity were considered: (1) Depth Filtration + GAC + Chlorination (Cl₂), (2) Membrane Bioreactor (MBR) + Cl₂, and (3) Ultrafiltration (UF) + Reverse Osmosis (RO) + Cl₂. Energy consumption varies across scenarios and is a sensitivity parameter:

$$\begin{aligned} GWP_{\text{scenario}} = & (E_{\text{treatment}} + E_{\text{chem}} + E_{\text{pump}} + E_{\text{tower}}) \cdot GWP_E \\ & + D_{\text{antiscalant}} \cdot GWP_{\text{antiscalant}} \\ & + D_{\text{biocide}} \cdot GWP_{\text{biocide}} \\ & + \text{direct treatment process emissions} \end{aligned} \quad (2.9)$$

Lastly, the user can choose different inputs for the CoC of the wastewater and freshwater scenarios, and the model will show the net water saving measured as a difference in blowdown between scenarios A and B:

$$\text{NWS} = \Delta V_{\text{blow}} \quad (2.10)$$

$$V_{\text{blow}} = \frac{r_{\text{evap}}}{\text{CoC} - 1} \quad (2.11)$$

where:

- **NWS** net water saving [m³/m³]

- ΔV_{blow} difference in blowdown volume between scenarios [m³/m³]
- V_{blow} blowdown volume [m³/m³]
- r_{evap} evaporation ratio [–]
- **CoC** cycles of concentration [–]

3. RESULTS

The LCI results are structured around three impact categories: GWP, cumulative energy demand (CED), and conventional freshwater supply (Scenario A) and freshwater displacement evaluated for wastewater reuse (Scenario B). All results are reported per functional unit (1 m³ makeup water delivered to the cooling tower). A summary of the comparative findings is presented in *Table S2*, with detailed breakdowns in *Tables S1*, *S3*, and *S4*.

3.1. Global Warming Potential

The reuse scenario carries approximately twice the GWP burden of the freshwater scenario. As shown in *Table S1* and *Figure 2*, electricity consumption is the dominant contributor to GWP in both scenarios, consistent with the findings of Wenzel and Radgen in 2023 [9], who identified electricity and water as responsible for over 97% of cooling tower environmental impacts. Within the electricity component, treatment energy accounts for roughly 80% of the inter-scenario GWP difference, reflecting the additional energy required by the depth filter + GAC + chlorination train for reclaimed water compared to simple freshwater conditioning. Tower operation energy, recirculation pumping, and fan power are identical across both scenarios, as they are governed by thermal load rather than water source.

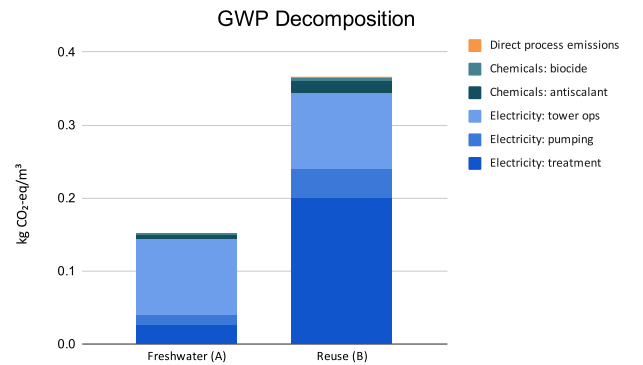


Fig. 2: Decomposition of GWP by emission source.

Chemical production emissions, disaggregated by antiscalant and biocide using substance-specific Ecoinvent 3.9 emission factors, contribute a modest but non-negligible share of total GWP (*Table S1*). The reuse scenario requires approximately three times the chemical dosing of freshwater, driven by the higher TDS of reclaimed water (800 vs. 200 mg/L) and more aggressive Legionella management requirements [10]. Direct treatment process emissions from chlorination byproducts (THMs/DBPs) were included for completeness, but are negligible compared to the electricity and chemical components.

3.2. Energy Intensity

The energy intensity results, disaggregated by treatment, pumping, and tower operation, are presented in *Figure 3*. Treatment energy is the dominant differentiator between scenarios and the primary engineering lever available for reducing the environmental penalty of reuse. This finding aligns with Akhouni et al. [2], who demonstrated that treatment train selection determines the viability of wastewater reuse for cooling applications. Tower operation energy, the largest energy component in both scenarios, does not differ between water sources and therefore does not influence the comparative assessment.

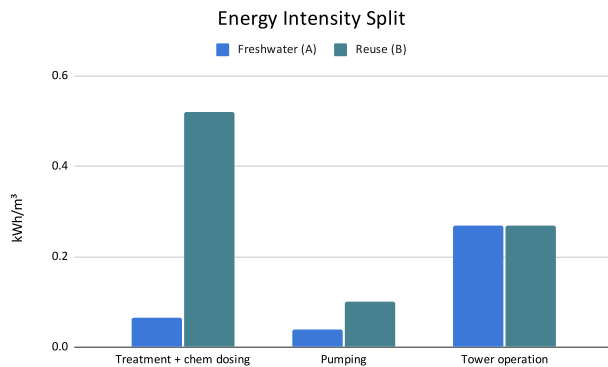


Fig. 3: Energy intensity split.

Under the UF+RO sensitivity case, reuse energy intensity rises to over four times that of freshwater, reinforcing the conclusion that membrane-based treatment is disproportionately energy-intensive for cooling tower applications where high-purity water is not required. However, membrane-based treatment produces significantly higher quality permeate with lower TDS, which would enable higher cycles of concentration potentially matching or exceeding the CoC achievable with freshwater. This tradeoff between treatment energy and operational water efficiency complicates a simple comparison: while UF+RO increases the energy intensity by a factor of four the resulting improvement in COC from 3.5 to 6 or higher would reduce blowdown volume, chemical consumption, and associated emissions. The net effect depends on the relative magnitude of these opposing factors, which warrants further investigation through an integrated optimization rather than the one-variable-at-a-time sensitivity presented here.

3.3. Freshwater Displacement

Freshwater displacement is the category where wastewater reuse delivers its defining environmental benefit. The reuse scenario withdraws zero freshwater from nature by definition, displacing the full volume of freshwater that would otherwise be required. When weighted by the AWARE2.0 scarcity characterization factor [13], the avoided water-scarcity impact is presented in *Table S2*. This result is invariant across all sensitivity scenarios, regardless of treatment train, grid carbon intensity, or cycles of concentration, making it a robust finding of the assessment.

However, the net freshwater benefit is partially offset by

indirect water consumption embedded in the energy and chemical inputs to both scenarios. Thermoelectric power generation in the US consumes approximately 1.8 L of freshwater per kWh through evaporative cooling at the power plant [14]. Applied to the energy intensities in this study, the indirect water footprint of electricity is 1.602 L/m³ for the reuse scenario and 0.675 L/m³ for freshwater, a difference of 0.927 L/m³ attributable to the higher treatment energy of the reuse train.

Chemical production carries embedded water costs, and Stokes and Horvath estimate roughly 10 L/kg for sodium hypochlorite and phosphonate-based antiscalants, which translates to about 0.008 L/m³ for reuse and 0.003 L/m³ for freshwater. Adding that to the electricity numbers, reuse about 1.61 L/m³ of indirect water versus 0.68 L/m³ for freshwater, so that is an additional 0.93 L/m³.

To put that in perspective, we are displacing 1,000 L/m³ of freshwater and paying back less than one liter in upstream water costs. That's under 0.1%, so the net displacement is still effectively 1.0 m³ avoided per m³ of makeup delivered. Reporting the upstream water costs is important because it shows the coupling between the energy and water dimensions. The additional electricity required by the reuse treatment train not only increases GWP, but also introduces secondary water burden through thermoelectric generation. While the magnitude is negligible relative to the direct displacement, omitting it would result in an incomplete system boundary. As the grid transitions toward wind and solar generation, this indirect water penalty will shrink alongside the GWP penalty, further strengthening the case for reuse over the infrastructure's lifetime.

3.4. Grid Sensitivity and GWP Breakeven

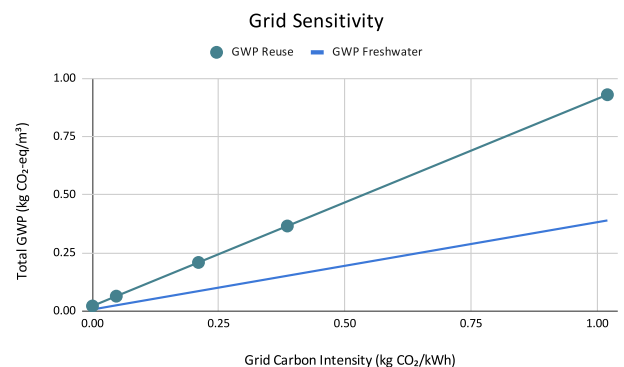


Fig. 4: GWP sensitivity to grid carbon intensity.

Because electricity dominates the GWP profile (see *Figure 2*), grid carbon intensity is the most influential parameter in determining the magnitude of the reuse GWP penalty. The sensitivity results are presented in *Table S3* and *Figure 4*. At coal-heavy grid intensities, the GWP gap between scenarios widens substantially. As grid carbon intensity decreases toward renewable-dominated systems, the gap narrows and approaches a small residual attributable only to chemical production and direct process emissions. Even under a fully decarbonized grid, a small residual GWP difference persists between the two scenarios, attributable to the higher

chemical production and direct process emissions associated with reuse. However, this residual is two orders of magnitude smaller than the difference at current grid intensities, confirming that grid decarbonization effectively eliminates the GWP disadvantage of reuse.

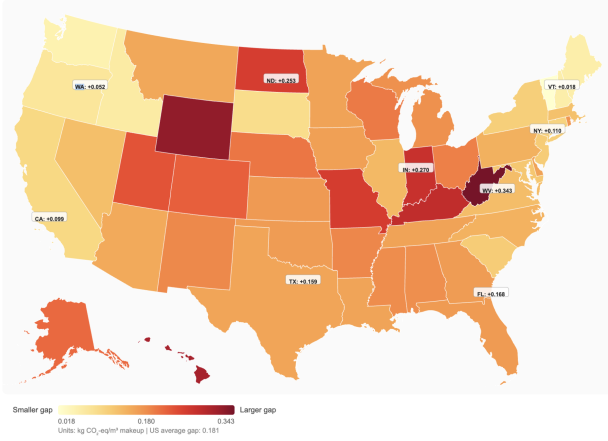


Fig. 5: GWP sensitivity on US state level.

This convergence pattern is significant for long-term infrastructure planning; data centers investing in cooling water systems today will operate them for 20+ years, during which grid decarbonization is expected to continue. According to NLR’s 2023 Standard Scenarios, the Mid-case projects a 95% net decarbonization of the US electricity sector by 2050 relative to 2005 levels [15], with annual electricity-sector CO₂ emissions declining by 81% by 2035 alone. Under this trajectory, the US average grid emission factor would decline from today’s ~ 0.386 kg-CO₂/kWh to approximately 0.05 – 0.08 kg-CO₂/kWh by mid-century comparable to France’s current nuclear-heavy grid. At that intensity, the GWP difference between reuse and freshwater shrinks to roughly 0.04 kg CO₂-eq/m³ (Table S3), while the freshwater displacement benefit remains unchanged at 1.0 m³ avoided per m³ makeup. A cooling system commissioned in 2025 and operated through 2050 would therefore spend the majority of its service life under grid conditions where the GWP penalty of reuse is negligible, while its water savings accrue at full value throughout.

3.5. Cycles of Concentration, Chemical Loading, and Cross-Impacts

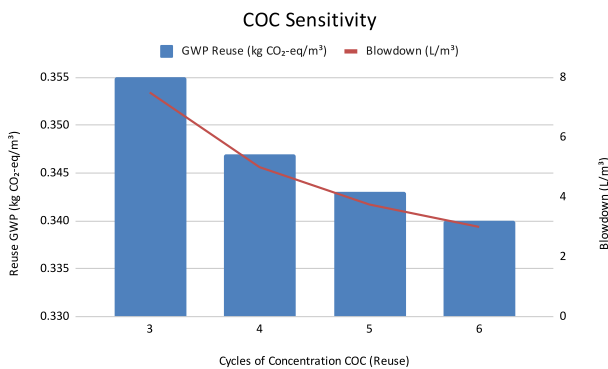


Fig. 6: Cycles of concentration sensitivity

Table S4 summarizes the operational parameters, including CoC, blowdown ratios, chemical loads, and their GWP contributions. The lower CoC achievable with reclaimed water as a consequence of its higher TDS cascades into increased blowdown volume and proportionally higher chemical consumption. The sensitivity of GWP to CoC variation is shown in Figure 6. While the effect is secondary compared to grid intensity and treatment train selection, CoC optimization represents a practical operational lever for facilities already committed to reuse, particularly for reducing water losses through blowdown minimization.

4. DISCUSSION

Given the high energy demand required for wastewater treatment, the GWP of the reuse case is higher across the board—regardless of the varying grid carbon intensities in the sensitivity analysis. However, a limitation of this analysis is that the wastewater would likely need to be treated by the municipal wastewater treatment facility. Indeed, the municipality is assisting the data center by providing water usable for cooling, but if the water is otherwise their responsibility to treat before discharge to surface waters, should the impacts of treatment not be borne by them?

This analysis centers on the environmental costs and impacts of material and energy flows, but not the embodied impacts of the facility’s construction. While the model attributes the material and energy flows of wastewater treatment to the data center—because different degrees of treatment may be required for reuse in cooling towers as opposed to typical surface water discharge—the facility construction and maintenance remains a municipal responsibility, and is thus out of the scope of our model. This balance of accounting for flow impacts and ignoring embodied impacts addresses the uncertainty of where responsibility of impacts lies, should such a supply arrangement arise between a data center and a municipality. It also allows our scope to focus on a functional unit of 1 m³ of cooling water.

While the electricity costs are more than double in the reuse case, the costs of actually procuring the fresh water costs an order of magnitude more [16]. Although our model did not include the possibility of retreating blowdown water, it is becoming a more common practice with hyperscalers. However, this will never form a fully circular water lifecycle, as water is still evaporating in the cooling process—hence why blowdown is necessary to maintain low concentrations of minerals that form scale on the equipment. In this way, any cooling solution that involves evaporation requires makeup water, and because it costs US cities more to treat and discharge wastewater than it does to procure fresh water, cities around the country would likely flock to the possibility of offloading some of their wastewater. The primary and secondary treatments, which the city normally would take care of, would double the energy requirements of the reuse case in our model. Unless a data center is exceptionally close to a city, it’s unlikely that the city would be able to send untreated wastewater all the way to the data center to be fully treated. It is challenging to guess what kind of bargain municipal water treatment systems may strike with data centers, but it is clear that data centers

should consider this partnership, if they want to maintain a synergistic relationship with their neighboring communities.

5. CONCLUSION

As data centers expand into water-scarce regions, the industry faces a growing tradeoff between conserving freshwater and increasing the energy required to keep facilities cool. This paper compares two cooling water supply options for data centers in arid regions: conventional freshwater and reclaimed municipal wastewater. Because cooling towers consume large amounts of water, we examine whether the water-saving benefits of reuse outweigh the added environmental burden from tertiary treatment, pumping, and chemical use. Using a comparative LCA, we evaluate both systems per cubic meter of cooling tower makeup water across three impact categories: GWP, energy demand, and freshwater displacement. Wenzel and Radgen (2023) show that electricity and water use dominate cooling tower impacts, with electricity and water consumption being responsible for more than 97% of impacts across categories. Their findings also support focusing mainly on operational impacts rather than an end to end analysis. Our results reveal a strong tradeoff between water conservation and carbon emissions. Wastewater reuse eliminated freshwater withdrawal entirely, making it the strongest option for reducing water scarcity impacts. However, the reuse scenario produced roughly double the GWP and energy demand of the freshwater because of additional treatment and pumping requirements. Reclaimed water also required greater chemical dosing due to higher TDS and increased scaling and biofouling risks. One of the study's most important findings was that the emissions gap between reuse and freshwater decreases significantly as electricity grids become cleaner. Under a 100% renewable grid, the GWP difference shrank from 0.540 to 0.015 kg-CO₂-eq/m³, showing how grid decarbonization could improve reuse sustainability over time. Ultimately, our paper concludes that freshwater currently performs better for energy and carbon impacts, while reclaimed wastewater performs better for water conservation, suggesting that reuse may become a more environmentally favorable long-term cooling strategy in regions facing severe water scarcity.

ACKNOWLEDGMENTS

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DATA AVAILABILITY

See Supplementary Information.

DISCLOSURES

Excel modeling was performed with the assistance of AI-based tools, including GPT-4, Sonnet 4.6, and ClaudeCode, used as productivity aids. Grammarly was used for proofreading. Evaluations and interpretations were developed and verified by the authors.

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