



WATER USAGE EFFECTIVENESS (WUE™): A GREEN GRID DATA CENTER SUSTAINABILITY METRIC

EDITOR:
Michael Patterson, Intel

CONTRIBUTORS:
Dan Azevedo, Symantec
Christian Belady, Microsoft
Jack Pouchet, Emerson

Executive Summary

The Green Grid (TGG) is a global consortium of companies, government agencies, and educational institutions dedicated to advancing energy efficiency in data centers and business computing ecosystems. TGG has developed a new metric to complement the series of metrics it has introduced in the past few years, which includes power usage effectiveness (PUE™), data center energy productivity (DCeP™), energy reuse effectiveness (ERE™), data center compute efficiency (DCcE™), and others. The Green Grid proposes this new metric to address water usage in data centers, which is emerging as extremely important in the design, location, and operation of data centers in the future. The new water usage effectiveness (WUE™) metric—combined with the PUE and carbon usage effectiveness (CUE™) metrics—enables data center operators to quickly assess the water, energy, and carbon sustainability aspects of their data centers, compare the results, and determine if any energy efficiency and/or sustainability improvements need to be made. Since PUE has received broad adoption in the industry, the WUE metric is a natural extension of PUE and extends the family of xUE metrics.

While xUE metrics address various key energy and sustainability elements in the data center, The Green Grid continues to drive the development of more advanced metrics such as data center productivity. To promote these metrics and encourage greater data center energy efficiency for businesses, academia, and governments around the world, The Green Grid will continue to publish white papers, technical briefs, books, and articles, along with hosting tech forums that provide detailed guidance on using these metrics and developing alliances with other organizations that promote a similar vision and goals.

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I. Introduction

The Green Grid believes that several metrics can help IT organizations better understand and improve the sustainability of their existing data centers, as well as help them make smarter decisions on new data center deployments.

Why the need for improved sustainability? Because data center energy consumption, carbon emissions, and water usage are affecting companies' decisions on growth, location, and outsourcing strategies. The power usage effectiveness (PUE™) metric has already proved to be a great industry tool for measuring infrastructure energy efficiency. However, it is important for the industry to continue driving the effective use of resources to maximize operational efficiency and reduce the impact on resources and the environment. With more sustainable data centers, IT organizations can better manage increased computing, network, and storage demands and at the same time lower their energy costs and reduce the total cost of ownership (TCO)—all while remaining competitive and able to meet future business needs. Clearly, the future presents risks, especially when it comes to carbon taxation and water costs and rights. Organizations that proactively focus on these issues will lower their business risks, increase their potential for growth, and better manage their environmental costs.

II. Sustainability Metrics: PUE, CUE™, and WUE™

Ideally, the metrics and processes established to address data center sustainability will help organizations first determine if an existing data center can be optimized before moving ahead with a new data center. For this reason, The Green Grid recently introduced the carbon usage effectiveness (CUE) metric to address carbon emissions and now introduces the new water usage effectiveness (WUE) metric to address water usage in data centers. Both carbon emissions and water usage are emerging as extremely important considerations in the design, location, and operation of data centers in the future. The combination of PUE, CUE, and WUE enables

data center operators to quickly assess important sustainability aspects in their data centers, compare the results, and determine if they need to make any energy efficiency and/or sustainability improvements. WUE represents the third metric (along with PUE and CUE) in the xUE family of metrics, a series designed to help the data center community better manage energy, environmental, societal, and sustainability parameters associated with building, commissioning, operating, and de-commissioning data centers.

Like PUE and CUE, the WUE metric uses the familiar value of IT Equipment Energy as its denominator. Once determined for PUE or CUE, the same value should be used as the denominator for this new metric as well. This commonality of structure will both ensure the metrics stay linked and speed their adoption.

Unlike PUE, WUE and CUE have dimensions (covered in Section III below), while PUE is unit-less; its value is energy divided by energy. Another important difference is the range of values. PUE has an ideal value of 1.0, implying that all energy used at the site goes to the IT equipment. There is no theoretical upper boundary for PUE. CUE and WUE both have an ideal value of 0.0, indicating that no carbon or water use is associated with the data center's operations. CUE and WUE also have no theoretical upper boundary, like PUE. (For further information regarding PUE calculations, please see [The Green Grid White Paper #22, Usage and Public Reporting Guidelines for The Green Grid's Infrastructure Metrics \(PUE/DCiE\)](#).¹)

All three metrics cover the operations of the data center, but they do not cover the full life-cycle environmental burden of the data center and IT equipment. For example, attempting to determine the water use in the construction of the data center or in the manufacturing of the IT equipment would make the WUE metric far too difficult to measure, calculate, or use. The Green Grid deems the full life cycle to be important to the sustainability of the industry but chose, for practical considerations, to exclude it from the WUE metric at this time. Full life-cycle considerations will be considered in future TGG efforts. For now, WUE is specifically limited to water use in processes due to site operations and source energy generation (similar to Scope 1 and Scope 2 greenhouse gas (GHG) emissions²).

III. Water Usage Effectiveness (WUE)

The metric for water usage in the data center is defined at a high level as:

$$\text{WUE} = \frac{\text{Annual Water Usage}}{\text{IT Equipment Energy}} \quad (1)$$

The units of WUE are liters/kilowatt-hour (L/kWh).

¹ <http://www.thegreengrid.org/en/Global/Content/white-papers/Usage%20and%20Public%20Reporting%20Guidelines%20for%20PUE%20DCiE>

² <http://www.epa.gov/greeningepa/glossary.htm#s>

Water use associated with the data center is a complex topic at many levels. With WUE, the issue of a “source-based” versus “site-based” metric must be considered. The main issue is that water use or changes to a site’s water use strategy generally affects other site use parameters and also can affect the supply chain for different utilities. A reduction in water use on-site can be accomplished a number of ways. The most attractive way is simply to employ optimal design, then increase operational efficiencies and tune the existing systems. Re-commissioning a facility can accomplish this. The industry is replete with horror stories of data centers where one computer room air conditioning (CRAC) unit is dehumidifying while another is humidifying—together wasting both water and energy. In addition, many data centers have yet to take advantage of the ASHRAE 2008 extended environmental envelope where recommended minimum humidity levels have been reduced to 5.5°C (42°F) dew point.

Beyond these changes, water use reductions generally have adverse trade-offs with increased energy use from increased chemical use (in water treatment systems). A rise in energy use has specific effects on the “site” as well as on the “source.” As mentioned, if the site reduces its water use, there could be an associated energy cost. This trade-off may be attractive at the site level—a decrease in water use in exchange for an increase in kilowatt-hours purchased or generated. However, if the goal is to minimize water use at the regional or watershed level, then the change may actually have an adverse impact that needs to be considered. It takes a significant amount of water to generate electricity. The amount of water depends on the generation method used, but the majority of electricity generation today is still very water intensive.³ So reducing water use at the site may increase electricity use, which will likely result in increased water use at the power-generation source. Depending on many factors like location, business strategy, and financial considerations, increasing water use and decreasing energy use may be the desired outcome, or increasing energy use and decreasing water use (as in a desert location) may be the desired outcome. Regardless of the desired outcome PUE, CUE, and WUE are helpful tools to enable business decisions.

For example, a data center can choose to use a direct expansion (DX) cooler, which needs no water, instead of a cooling tower-based chiller, which uses the evaporation of water as a heat rejection mechanism. Certainly the site will use less water with a DX-based cooling system. But these systems can be less efficient than evaporative-based technologies, requiring a larger amount of energy. Depending on the energy-generation method, this additional load could mean increased water use at the power plant. In this case, the water use may simply be shifted from one site to another, while the ecosystem’s total water use may actually go up.

³ For example, of the 1,404 billion gallons of water withdrawals used in the State of Minnesota in 2008, more than half (838 billion gallons) went to power generation, with public supply a distant second at 217 billion gallons. http://www.dnr.state.mn.us/waters/watermgmt_section/appropriations/wateruse.html

Therefore, The Green Grid believes that, at a minimum, both source- and site-based WUE metrics are beneficial. Part of TGG's efforts going forward will be to further explore these different levels and make recommendations on the specifics of each.

Analogous to the direct (Scope 1) and indirect (Scope 2) definitions used to describe carbon emissions, TGG defines the new metrics as:

- **WUE**, a site-based metric that is an assessment of the water used on-site for operation of the data center. This includes water used for humidification and water evaporated on-site for energy production or cooling of the data center and its support systems (similar to carbon Scope 1).
- **WUE_{source}**, a source-based metric that includes water used on-site and water used off-site in the production of the energy used on-site. Typically this adds the water used at the power-generation source to the water used on-site (similar to carbon Scope 2).

$$\text{WUE} = \frac{\text{Annual Site Water Usage}}{\text{IT Equipment Energy}} \quad (2)$$

$$\text{WUE}_{\text{source}} = \frac{\text{Annual Source Energy Water Usage} + \text{Annual Site Water Usage}}{\text{IT Equipment Energy}} \quad (3)$$

To determine the source energy water usage, the facility's total energy use must be known. The total facility energy is the numerator in PUE and is defined as the average energy used over a year as measured by the utility or on-site generation—the energy dedicated solely to the data center and its infrastructure operations (important in mixed-use buildings that house data centers as one of a number of functions).

Once known, this value can then be combined with an *energy water intensity factor* (EWIF) that is based on the water used to produce the energy. Further discussion of EWIF and local values for thermoelectric generation is included in Appendix A, which addresses both technology-based EWIF values that are region-independent and some location-specific values. More specific regional information may be available, depending on the territory. One source for local values is a National Renewable Energy Laboratory (NREL) technical report, *Consumptive Water Use for U.S. Power Production*.⁴ EWIF for other sources beyond thermoelectric generation will be further developed, but initially solar, wind, and hydro power are taken as 0. The U.S. national average is 1.8 liters/kWh. The annual water use from source energy can be determined by allocating water use by a percentage of the year from the various sources. Then WUE_{source} can be found as:

⁴ *Consumptive Water Use for U.S. Power Production*, P. Torcellini, N. Long, and R. Judkoff, 2003, NREL/TP-550-33905, <http://www.nrel.gov/docs/fy04osti/33905.pdf>

$$WUE_{\text{source}} = [EWIF \times PUE] + \frac{\text{Annual Site Water Usage}}{\text{IT Equipment Energy}} \quad (4)$$

The IT Equipment Energy (used in Equations 1 through 4) is defined as the equipment energy over the year that is used to manage, process, store, or route data within the data center. PUE is the annual PUE.

It is also important to understand the components for the loads in the metrics, which can be described as:

- **IT Equipment Energy.** This includes the load associated with all of the IT equipment, including compute, storage, and network equipment, along with supplemental equipment such as KVM switches, monitors, and workstations/laptops used to monitor or otherwise control the data center.
- **Total Facility Energy.** This includes all IT equipment energy as described above, plus everything that supports the IT equipment load, such as:
 - Power delivery components (e.g., UPS, switch gear, generators, PDUs, batteries, and distribution losses external to the IT equipment)
 - Cooling system components (e.g., chillers, CRACs, DX air handler units, pumps, and cooling towers)
 - Other miscellaneous component loads such as data center lighting
- **Annual Water Use (Site and Source).** This includes all water used in the operations of or for the data center, including:
 - Humidification
 - Water consumed for cooling the data center or data center-associated power-generating equipment (including cooling tower evaporation, blowdown, and drift)
 - Water used in the production of energy. The water used in energy production off-site is only included in the WUE_{source} metric. The water used in energy production on-site is included in both WUE and WUE_{source} .

IV. Appropriate Use of WUE and WUE_{source}

In practice, WUE is expected to be the more easily measured and commonly reported of the two metrics. It also is the simplest metric for driving optimization of an operational site's water use. This can be accomplished by such actions as:

- Reduce IT energy use, thereby reducing cooling demand, thereby reducing water consumption.
- Ensure the humidity control system is optimized and the data center is running at the low end of the ASHRAE-recommended guidelines for humidity (5.5°C dew point).
- Optimize cooling tower operations (if they are used) to increase cycles of concentration.

- Implement all appropriate best practice airflow management strategies to improve cooling efficiency.
- Operate the data center at or near the ASHRAE-recommended upper limit for temperature, as this will (depending on the cooling plant) allow warmer chilled water and require less evaporation of water to produce it.

WUE_{source} , on the other hand, should be the metric used for data center decisions related to site planning and data center design, helping with such considerations as:

- The total water footprint of potential sites should be determined, including water used in energy production.
- The cooling system design chosen may reduce water use on-site but possibly boost energy use and increase the data center's total impact on water usage.
- Selecting a dry, cool site (with the option of air-side economization) versus a hot, humid site could reduce on-site and off-site (at the power-generation station) water use. WUE would improve, but WUE_{source} would show an even greater improvement.

The Green Grid recognizes that both WUE and WUE_{source} have value and that each has a separate but closely related applicability. At a minimum, existing sites should use WUE in their operational optimizations and use WUE_{source} for decisions that affect water and energy use beyond the data center itself.

In summary, WUE provides a way to determine:

- Opportunities to improve a data center's sustainability
- How a data center compares with similar data centers
- If the data center's operators are improving its designs and processes over time
- Opportunities for the consideration of alternate cooling strategies or renewable power sources that use no water
- Trade-offs in energy efficiency strategies by comparing PUE, CUE, and WUE under various use scenarios, operating conditions, etc.

In the short term, The Green Grid suggests that data center owners begin thinking about how to adopt the WUE and WUE_{source} metrics in their own operations to improve their own sustainable practices. While these metrics are not fully defined at this point, The Green Grid feels it is important to think about both carbon emissions and water usage in data centers and begin calculating the xUE family of metrics (PUE, CUE, and WUE) in their operations, even if the method currently requires estimations and calculations versus direct measurement. In addition, The Green Grid encourages data center owners to share their respective PUE, CUE, and WUE results, which will help individual data center owners analyze their measurement methodologies as well as understand how their results compare with the rest of the industry.

V. Long Term

Clearly, this brief white paper leaves out much of the detail on how to calculate, measure, and use WUE. The Green Grid plans to expand on this metric in further detail but, in the spirit of industry transparency and urgency, released this white paper early to start the socialization process of WUE and the other xUE metrics as well as encourage industry discussion. Items already being considered for future white papers include:

1. Detailed process on determining WUE
2. Further development of the site versus source issue for WUE and how and when to use each
3. Process for determining WUE for mixed-use buildings
4. Further review of multiple water sources for a site
5. The details of water quality (generally the chemical constituents), water locality, temperature, and the same will affect the sustainability criteria of a particular water-use scheme.
6. How to deal with re-used or reclaimed energy or water for other users outside the data center boundary (water reclaimed and re-used within the data center boundary will improve WUE and show the benefit)
7. Understanding the CO₂/greenhouse gas and embedded energy content of delivered water (kgCO₂/liter). This needs to be considered because water treatment itself can be an energy-intensive process. Desalination of seawater uses far more energy than extracting water from a snowmelt-sourced reservoir. Pumping and delivery of water is also an important component, as is evaporation of water that may occur in its distribution. In the future, these factors could be included in a WUE_{scope3} metric. Other water parameters also can affect the overall balance. Is the water used warm or cold, and was energy expended to get it that way?
8. Incorporation of developing water and carbon accounting practices
9. Life-cycle aspects of carbon, water, and energy

One can envision a future scenario where data center location, design, architecture, and infrastructure decisions include PUE, CUE, and WUE as well as the full source-energy and water composition of delivered, locally produced and stored energy and natural resources. An increased understanding of #6 in the above list will significantly aid meaningful discussions along these lines.

VI. Conclusion

The Green Grid feels the new CUE and WUE metrics will have the same positive impact on the industry as did PUE. This is a huge opportunity for the industry to rally around these metrics, and The Green Grid encourages other industry stakeholders to participate in developing WUE with The Green Grid. Moving forward, The Green Grid recommends the use of PUE, CUE, and WUE, with the understanding that these metrics will be refined in the future.

VII. About The Green Grid

The Green Grid is a global consortium of companies, government agencies, and educational institutions dedicated to advancing energy efficiency in data centers and business computing ecosystems. The Green Grid does not endorse vendor-specific products or solutions, and instead seeks to provide industry-wide recommendations on best practices, metrics, and technologies that will improve overall data center energy efficiencies. Membership is open to organizations interested in data center operational efficiency at the Contributor, General, or Associate member level. Additional information is available at www.thegreengrid.org.

VIII. Appendix A. Energy Water Intensity Factor

The energy water intensity factor (EWIF) is needed to calculate WUE_{source} . The EWIF value is a measurement of a volume of water used for generating energy. Many energy-generation methods use significant amounts of water in their operations (often for cooling). The actual water consumption of a data center's energy generation at the source needs to be considered for activities such as site selection and system design.

Table A-1. TGG-recommended EWIF values if local specific data is not known

Production method	Suggested EWIF (L/kWh)	Comments
Hydro	0	While evaporation is the main source of water use in power generation, to the extent that reservoirs for hydroelectric plants lose more water to evaporation than thermoelectric plants due to cooling, the evaporation is not a marginal rate based on increases or decreases in energy use. If hydro is being built for your data center, use an EWIF of 68 L/kWh.
Solar (PV)	0	
Solar (Concentrated)	3.3	
Wind	0	
Coal	2.2	For coal with CO ₂ sequestration, use 2.8 L/kWh.
Nuclear	3.3	
Natural Gas	0.8	
Unknown	1.8	Per the U.S. Aggregate for Thermoelectric Plants

The EWIF values follow the calculation methodology used in the NREL *Consumptive Water Use for U.S. Power Production* technical report referred to in Section III of this paper, including a 5% generation loss for thermoelectric and a 9% transmission loss. The EWIF values above are derived from [Energy Demands on Water Resources, Report to Congress on the Interdependency of Energy and Water by the U.S. Department of Energy \(2006\)](#)⁵ as well as the NREL report.

Table A-2. U.S. Regional EWIFs adopted from *Consumptive Water Use for U.S. Power Production* (L/kWh)

Western Interconnect	1.4
Eastern Interconnect	1.9
Texas Interconnect	1.7
U.S. Aggregate	1.8

⁵ <http://www.sandia.gov/energy-water/docs/121-RptToCongress-EWwEIAcomments-FINAL.pdf>

Table A-3. U.S. State EWIFs adopted from *Consumptive Water Use for U.S. Power Production (L/kWh)*

State	EWIF	State	EWIF	State	EWIF
Alabama	0.53	Louisiana	5.91	Oklahoma	1.93
Alaska	1.17	Maine	1.10	Oregon	3.10
Arizona	1.21	Maryland	0.11	Pennsylvania	2.04
Arkansas	1.10	Massachusetts	0.00	Rhode Island	0.00
California	0.19	Michigan	1.89	South Carolina	0.98
Colorado	1.93	Minnesota	1.67	South Dakota	0.04
Connecticut	0.30	Mississippi	1.48	Tennessee	0.00
Delaware	0.04	Missouri	1.17	Texas	1.67
D.C.	6.09	Montana	3.63	Utah	2.16
Florida	0.53	Nebraska	0.72	Vermont	1.32
Georgia	2.27	Nevada	2.12	Virginia	0.26
Hawaii	0.15	New Hampshire	0.45	Washington	1.10
Idaho	0.00	New Jersey	0.26	West Virginia	2.23
Illinois	3.97	New Mexico	2.38	Wisconsin	1.85
Indiana	1.55	New York	3.22	Wyoming	1.85
Iowa	0.45	North Carolina	0.87		
Kansas	2.20	North Dakota	1.36		
Kentucky	4.16	Ohio	3.60		