Supplementary Information for The hidden water geography of U.S. hyperscale data centers in the AI era

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This Supplementary Information provides additional methodological detail, parameter choices, scenario summaries, robustness figures, and supporting tables for the main manuscript.

Contents

1 Supplementary Methods

1.1 Study design and accounting boundary

We estimate annual *operational* water *consumption* from U.S. hyperscale data centers using a facility-resolved framework that separates direct on-site cooling water consumption (Scope 1) from electricity-related water consumption attributable to grid electricity supply (Scope 2). The unit of analysis is the individual hyperscale facility i; facility-level estimates are then aggregated to states, balancing authorities (BAs), and hydrologic basins. We adopt Scope 1/Scope 2 terminology by analogy with greenhouse-gas reporting [1]: Scope 1 denotes water consumed directly at the facility for cooling, and Scope 2 denotes water consumed off site to generate the facility's electricity.

Throughout, we focus on **water consumption**: water removed from local availability, typically through evaporation, rather than gross withdrawals. The core boundary is operational and excludes embodied and supply-chain water. For each facility,

$$W_i^{\text{tot}} = W_i^{(1)} + W_i^{(2)}. \tag{1}$$

When water-intensity factors are expressed in L kWh^{-1} and electricity is expressed in kWh, the combined expression is

$$W_i^{\text{tot}} = 10^{-3} \left[\underbrace{I_{r(i)}^{\text{grid}} E_{i,\text{kWh}}^{\text{fac}}}_{\substack{\text{Scope 2:} \\ \text{electricity-related water}}} + \underbrace{\text{WUE}_i \frac{E_{i,\text{kWh}}^{\text{fac}}}{\text{PUE}_i}}_{\substack{\text{Scope 1:} \\ \text{direct cooling water}}} \right], \tag{2}$$

where the factor 10^{-3} converts litres to cubic metres.

1.2 Facility inventory

Facility coordinates, identifiers, and power attributes are drawn from a facility-level hyperscale inventory and electricity-attribution pipeline [2]. The main analysis uses 472 U.S. hyperscale facilities in the 12-month study window ending in March 2026 that have current nameplate-power estimates and the spatial information needed for grid, basin, and water-stress joins. The key power attribute is `current_mw`, denoted P_i (MW), interpreted as nameplate *facility-level* power rather than IT-only load.

1.3 Grid regions and generation mix

Each facility is assigned to a balancing authority $r(i)$ using a point-in-polygon join between facility coordinates and eGRID balancing-authority polygons [3]. For each BA r, generation shares $s_{r,f}$ by fuel or technology class f are obtained from eGRID-linked summaries and normalized to sum to one:

$$\sum_{f \in \mathcal{F}} s_{r,f} = 1. \tag{3}$$

The technology classes are coal, gas, nuclear, hydro, wind, solar, and other generation.

1.4 Hydrologic basins and water stress

Each facility is assigned to a HydroBASINS level-6 polygon $b(i)$ using a point-in-polygon join [4]. Baseline water-stress indicators are attached using the World Resources Institute Aqueduct Water Risk Atlas 4.0 [5, 6]. We use the continuous Aqueduct baseline water-stress score on the 0–5 scale and classify a facility or region as high stress when $S \geq 3$, corresponding to Aqueduct's high to extremely high stress range. Facilities falling outside polygon coverage or lacking a required spatial assignment are excluded from analyses requiring that join. We do not impute missing grid-mix or stress attributes.

1.5 Facility electricity model

Annual facility electricity is computed from nameplate facility-level power and an annual-average utilization factor u:

$$E_i^{\text{fac}} = P_i \times 8760 \times u, \tag{4}$$

where E_i^{fac} is in MWh yr^{-1}. When multiplied by water-intensity factors in L kWh^{-1}, electricity is expressed in kWh:

$$E_{i,\text{kWh}}^{\text{fac}} = 1000 E_i^{\text{fac}}. \tag{5}$$

Because P_i represents facility-level load, PUE is not applied to scale total facility electricity. PUE enters only when converting facility electricity to IT electricity for WUE-based Scope 1 calculations. Applying PUE to total facility electricity would double-count non-IT overhead.

1.6 Scope 1: direct cooling water

We estimate Scope 1 water consumption using Water Usage Effectiveness (WUE), a standardized metric defined in ISO/IEC 30134-9 as litres of site water use per kWh of IT electricity [7]. Annual IT electricity is recovered as

$$E_{i,\text{kWh}}^{\text{IT}} = \frac{E_{i,\text{kWh}}^{\text{fac}}}{\text{PUE}_i}, \tag{6}$$

and Scope 1 water consumption is

$$W_i^{(1)} = 10^{-3} \text{WUE}_i E_{i,\text{kWh}}^{\text{IT}}. \tag{7}$$

Because measured, facility-specific WUE is not consistently disclosed at national scale, we apply literature-grounded scenario windows (efficiency, baseline, and high-load) to bracket plausible operational intensities [8–11]. These values represent scenario assumptions rather than observed facility-level measurements.

1.7 Scope 2: electricity-related water

Scope 2 water consumption is computed by combining facility electricity demand with a BA-specific grid water-consumption intensity:

$$W_i^{(2)} = 10^{-3} I_{r(i)}^{\text{grid}} E_{i,\text{kWh}}^{\text{fac}}. \tag{8}$$

The BA-level grid water intensity is

$$I_r^{\text{grid}} = \sum_{f \in \mathcal{F}} s_{r,f} w_f, \tag{9}$$

where w_f is a literature-based operational water-consumption factor for technology class f [12, 13]. The baseline factor set is reported in Supplementary Table S1. This is a location-based attribution: facilities inherit BA-average generation mixes and water intensities. We do not incorporate power-purchase agreements, behind-the-meter generation, or contract-based claims in the core footprint because the objective is to attribute water consumption to the physical electricity system associated with each facility's location.

1.8 Hydropower attribution

Hydropower water-consumption factors depend on how reservoir evaporation is allocated among water, energy, flood control, navigation, recreation, and other reservoir purposes. Because this allocation is methodologically contested [14], we report a no-hydro sensitivity in which the hydropower water factor is set to zero. This sensitivity bounds the influence of reservoir-evaporation attribution on Scope 2 totals and maps.

1.9 Aggregation and stress metrics

Facility-level estimates are aggregated to facilities, states, balancing authorities, and hydrologic basins. We report Scope 1 primarily at the basin level because direct cooling water is hydrologically proximate to the facility. We report Scope 2 primarily at the BA level because electricity-related water is mediated by the regional power system. For BA-level stress overlays and benchmark maps, we use an MW-weighted mean siting-stress metric:

$$\bar{S}_r^{\mathrm{mw}} = \frac{\sum_{i:r(i)=r} P_i S_i}{\sum_{i:r(i)=r} P_i}. \tag{10}$$

This metric describes the stress exposure of hosted data-center capacity, not the exact stress conditions at all generators serving the BA.

1.10 Hotspot definitions

The main-text hotspot maps use pathway-specific screening definitions chosen for interpretability. For Scope 1, a basin is high burden if its total Scope 1 water is above the median among basins hosting hyperscale facilities. A basin is stress-qualified if Aqueduct baseline stress is ≥ 3 in the basin or in a touching neighbour. Scope 1 hotspots satisfy both conditions. The neighbouring-basin rule reduces false precision at basin boundaries and acknowledges that facility water sourcing and water-management systems may not align perfectly with polygon boundaries.

For Scope 2, a balancing authority is high burden if its total Scope 2 water is at or above the median among hosting BAs. Fossil-heavy supply is defined as coal plus gas generation share greater than 0.5. High stress is defined as MW-weighted mean siting stress $\bar{S}_r^{\mathrm{mw}} \geq 3$. The most restrictive Scope 2 class satisfies all three conditions: high Scope 2 burden, fossil-heavy supply, and high stress.

1.11 Benchmark comparison maps

The main-text Fig. 5 reports two pathway-specific benchmark comparisons. Each mapped value is the *potential reduction in water consumption*: the difference between the current estimate and the lower value that would remain if the region moved to the stated benchmark. These calculations rank where reductions would be largest under stated assumptions. They are not forecasts, cost curves, marginal causal effects, or engineering-feasibility assessments.

For Scope 1, benchmark water is obtained by scaling baseline Scope 1 according to scenario assumptions:

$$W^{(1)}_{i,\mathrm{bench}} = W^{(1)}_{i,\mathrm{base}} \frac{u_{\mathrm{bench}}}{u_{\mathrm{base}}} \frac{\mathrm{WUE}_{\mathrm{bench}}/\mathrm{PUE}_{\mathrm{bench}}}{\mathrm{WUE}_{\mathrm{base}}/\mathrm{PUE}_{\mathrm{base}}}. \tag{11}$$

Basin-level potential savings are

$$\Delta W^{(1)}_b = \sum_{i:b(i)=b} \left(W^{(1)}_{i,\mathrm{base}} - W^{(1)}_{i,\mathrm{bench}} \right). \tag{12}$$

For Scope 2, the benchmark compares each BA's grid water intensity with the 25th percentile among hosting BAs:

$$I^{\mathrm{target}}_r = \min \left\{ I^{\mathrm{grid}}_r, Q_{0.25}(I^{\mathrm{grid}}_r) \right\}. \tag{13}$$

Let $E^{\mathrm{fac}}_{r,\mathrm{kWh}} = \sum_{i:r(i)=r} E^{\mathrm{fac}}_{i,\mathrm{kWh}}$ denote total annual hosted facility electricity in BA r. Potential Scope 2 savings are

$$\Delta W^{(2)}_r = 10^{-3} \left(I^{\mathrm{grid}}_r - I^{\mathrm{target}}_r \right) E^{\mathrm{fac}}_{r,\mathrm{kWh}}. \tag{14}$$

The $\min\{\cdot\}$ operator ensures that BAs already at or below the benchmark are not assigned negative reduction potential.

1.12 Scenario windows and parameter justification

We evaluate internally consistent efficiency, baseline, and high-load scenarios by varying utilization, PUE, and WUE (Supplementary Table S1). The baseline scenario is the central parameter set used in the main text. The efficiency and high-load cases are bounding scenarios, while the no-hydro case isolates one Scope 2 attribution choice.

The utilization factor brackets uncertainty in realized load relative to nameplate capacity. Large hyperscale campuses can operate below peak nameplate capacity because of redundancy, phased buildout, and load variability. The PUE values span efficient hyperscale operation through higher-overhead operation [9, 11, 15]. The WUE values span lower-intensity, representative, and water-intensive operating regimes [8–10]. Under the facility-load interpretation, Scope 2 scales linearly with utilization, while Scope 1 scales with $u \times (\mathrm{WUE}/\mathrm{PUE})$.

2 Supplementary Results

2.1 National scenario sensitivity

Supplementary Table S2 reports national totals across the scenario set. Total operational water ranges from 204.91 GL yr^{-1} in the efficiency scenario to 450.60 GL yr^{-1} in the high-load scenario. The no-hydro sensitivity lowers Scope 2 from 225.74 to 128.35 GL yr^{-1} and lowers the total from 299.89 to 202.50 GL yr^{-1}. Scope 2 remains the larger component in all scenarios, although the gap narrows when hydropower attribution is removed.

2.2 Robustness of hotspot geography

Supplementary Fig. S1 shows that the Scope 1 hotspot geography is visually stable across the efficiency, high-load, and no-hydro scenarios. This stability reflects the fact that Scope 1 geography is driven primarily by siting and basin-level aggregation when WUE and PUE are applied as national scenario parameters.

Quantity	**Definition / units**	**Values**	**Notes**
u	Annual-average utilization	0.55 / **0.66** / 0.85	Efficiency / baseline / high-load.
PUE	Facility/IT electricity	1.15 / **1.25** / 1.40	Used only to recover IT electricity.
WUE	L $\mathrm{kWh}_{\mathrm{IT}}^{-1}$	0.2 / **0.8** / 1.5	Direct cooling-water intensity.
w_f	L kWh^{-1} by generation class	Coal 1.9; gas 0.7; nuclear 2.5; hydro 8.0; wind 0.0; solar 0.1; other 1.0	Baseline factor set.
High stress	Aqueduct score	$S \geq 3$	High to extremely high stress.
Scope 2 benchmark	Grid water-intensity target	$Q_{0.25}(I_r^{\mathrm{grid}})$	Lower-water comparator among hosting BAs.

Table S1: Key parameters and scenario values. Baseline values are shown in bold.

Scenario	**Electricity ($\mathrm{TWh\ yr}^{-1}$)**	**Scope 1 ($\mathrm{GL\ yr}^{-1}$)**	**Scope 2 ($\mathrm{GL\ yr}^{-1}$)**	**Total ($\mathrm{GL\ yr}^{-1}$)**	**Scope 1 (%)**	**Scope 2 (%)**	**Intensity ($\mathrm{L\ kWh}^{-1}$)**
Efficiency	96.56	16.79	188.11	204.91	8.20	91.80	2.12
Baseline	115.87	74.16	225.74	299.89	24.73	75.27	2.59
High-load	149.22	159.88	290.72	450.60	35.48	64.52	3.02
No-hydro	115.87	74.16	128.35	202.50	36.62	63.38	1.75

Table S2: National operational water summary across scenarios. Totals may not sum exactly because of rounding.

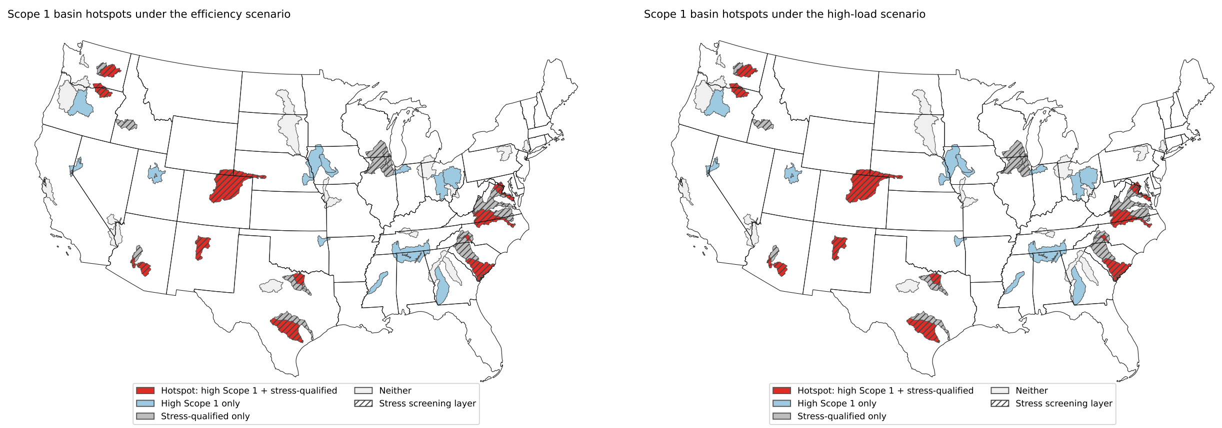
Supplementary Fig. S2 shows that the Scope 2 hotspot geography is stable across the efficiency and high-load scenarios but changes in some hydro-heavy western BAs under the no-hydro sensitivity. This indicates that hydropower attribution affects part of the Scope 2 map, while many eastern and southeastern elevated classes remain.

2.3 Concentration and rank stability

Supplementary Fig. S3 shows that cumulative concentration curves are similar across scenarios. Scope 2 remains more spatially concentrated than Scope 1 regardless of the scenario. Supplementary Fig. S4 compares regional burdens under alternative scenarios with the baseline. Scope 1 basin ranks are stable across scenarios, and Scope 2 BA ranks are stable across efficiency and high-load cases and only partially altered under no-hydro.

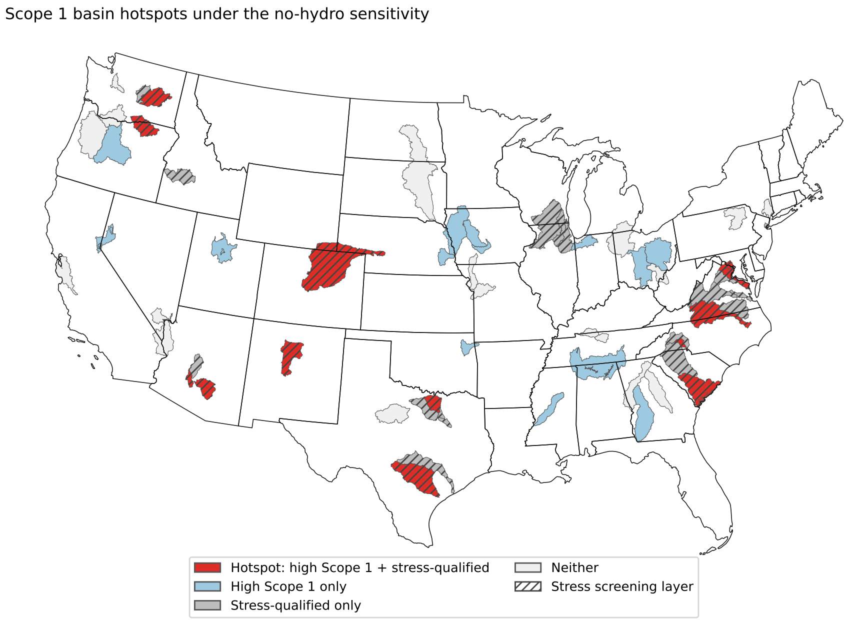
2.4 Bivariate diagnostic for Scope 2

Supplementary Fig. S5 combines grid water intensity with MW-weighted mean siting stress. It is not a map of total burden. Instead, it shows where relatively water-intensive electricity supply and stressed hosting exposure co-occur. The baseline and no-hydro panels isolate the role of hydropower attribution. Excluding hydropower shifts some hydro-heavy western BAs into lower grid-intensity classes, while many elevated regions outside the West remain.



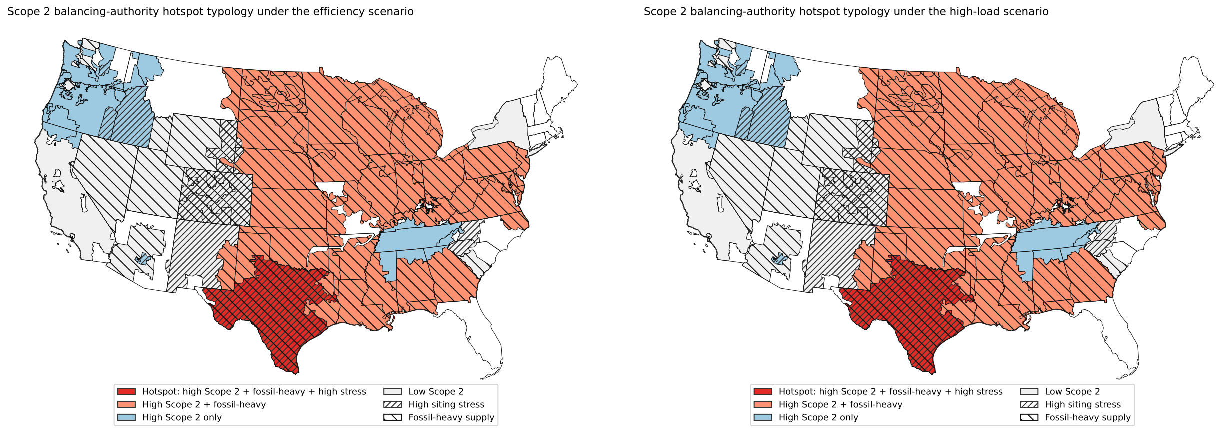
a, Efficiency

b, High-load



c, No-hydro

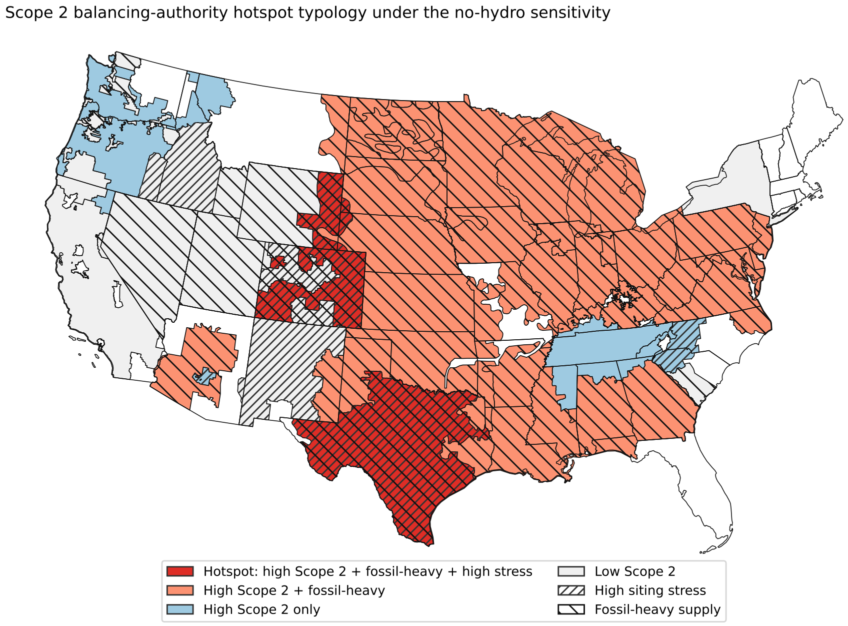
Figure S1: **Scope 1 basin hotspot robustness across scenarios.** Basins are classified using the same screening rule as in Fig. 2a of the main text. The hotspot geography is visually stable across the efficiency, high-load, and no-hydro scenarios, indicating that the main Scope 1 geography is driven primarily by siting and basin-level aggregation rather than by operating assumptions.


Scope 2 balancing-authority hotspot typology under the efficiency scenario

Scope 2 balancing-authority hotspot typology under the high-load scenario

a, Efficiency

b, High-load


Scope 2 balancing-authority hotspot typology under the no-hydro sensitivity

c, No-hydro

Figure S2: **Scope 2 balancing-authority hotspot robustness across scenarios.** BAs are classified using the same typology as in Fig. 2b of the main text. The efficiency and high-load panels are similar, indicating that operating assumptions primarily rescale Scope 2 burden rather than change its geography. The no-hydro panel shows the main substantive sensitivity: some hydro-heavy western BAs shift to lower classes when reservoir evaporation is excluded, whereas many eastern and southeastern BAs remain in elevated classes.

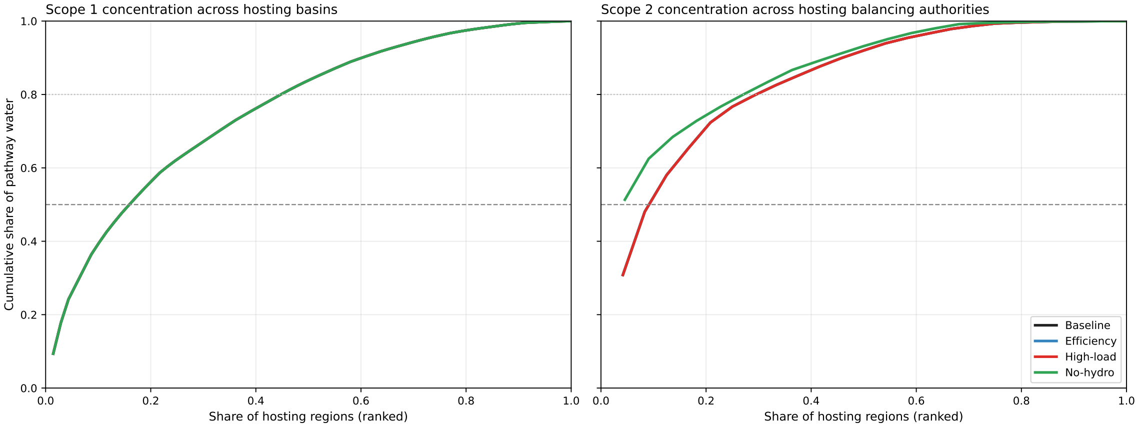


Figure S3: **Concentration robustness across scenarios.** Cumulative concentration curves for Scope 1 across basins and Scope 2 across balancing authorities are shown for all scenarios. Scope 2 remains more spatially concentrated than Scope 1.

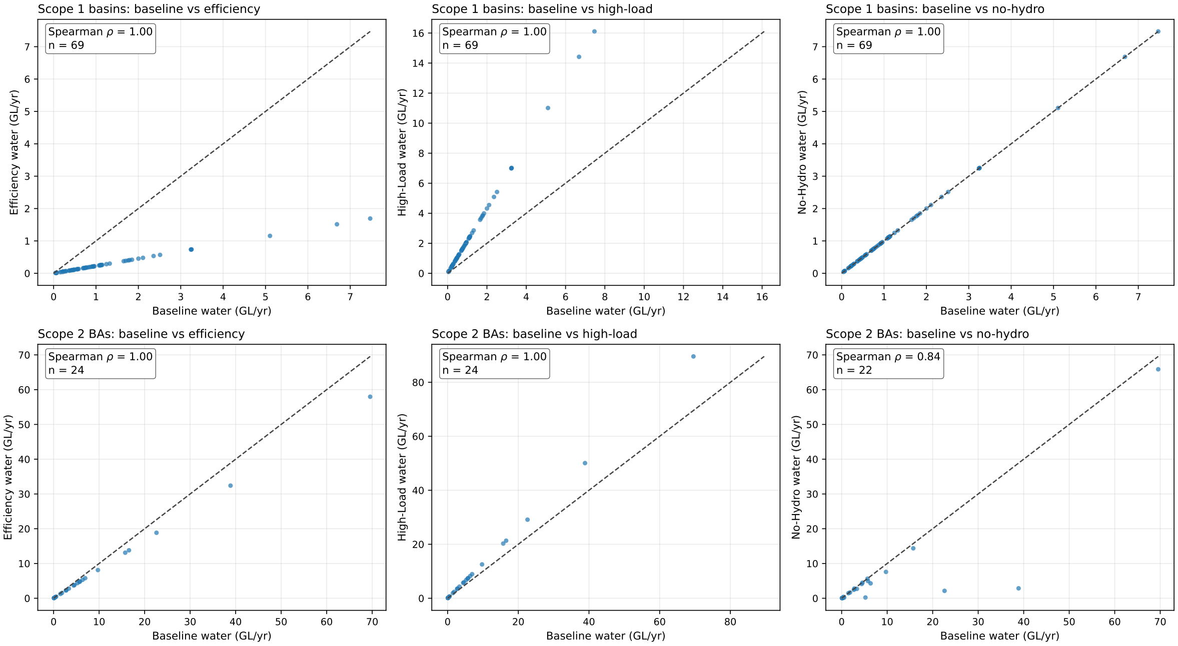
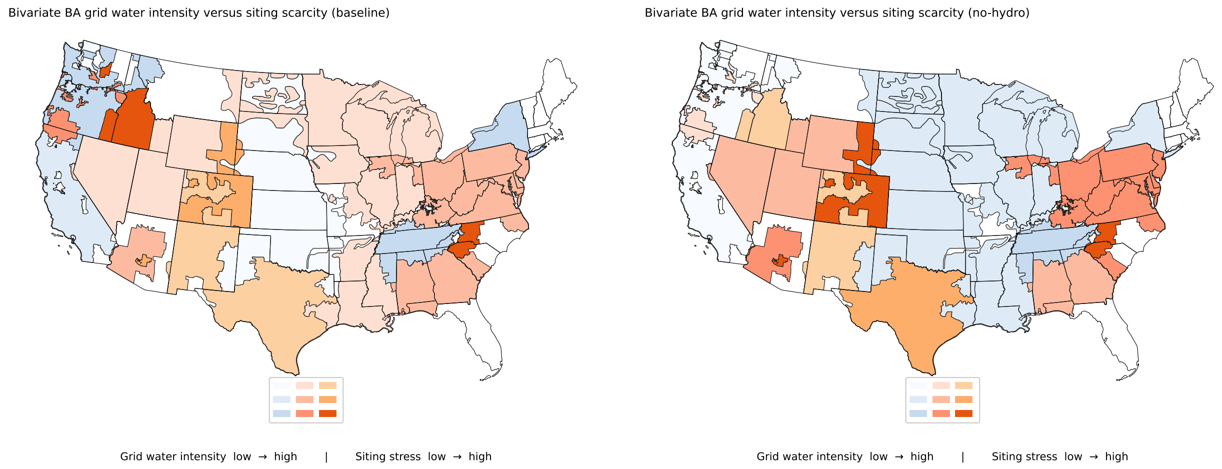


Figure S4: **Rank stability across scenarios.** Each panel compares baseline regional burden with the corresponding burden under an alternative scenario. Spearman correlations show that operating assumptions change absolute totals more than regional rank ordering.



a, Baseline **b**, No-hydro

Figure S5: **Bivariate balancing-authority grid water intensity versus siting stress.** Warmer upper-right classes indicate the joint occurrence of high grid water intensity and high siting stress. Excluding hydropower shifts some hydro-heavy western balancing authorities into lower grid-intensity classes, while many elevated regions outside the West remain.

3 Supplementary Tables

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State	MW	Scope 1 (GL/yr)	Scope 2 (GL/yr)	Total (GL/yr)	Total (ML/MW-yr)
Virginia	4,199	6.6 / **29.1** / 62.8	32.4 / **38.9** / 50.0	39.0 / **68.0** / 112.8	9 / **16** / 27
Ohio	2,621	4.1 / **18.2** / 39.2	20.2 / **24.3** / 31.2	24.3 / **42.4** / 70.4	9 / **16** / 27
Oregon	2,443	3.8 / **16.9** / 36.5	109.9 / **131.9** / 169.9	113.8 / **148.9** / 206.4	47 / **61** / 84
Iowa	1,766	2.8 / **12.3** / 26.4	12.1 / **14.5** / 18.7	14.9 / **26.8** / 45.1	8 / **15** / 26
Texas	1,193	1.9 / **8.3** / 17.8	4.8 / **5.7** / 7.4	6.7 / **14.0** / 25.2	6 / **12** / 21
Arizona	835	1.3 / **5.8** / 12.5	6.2 / **7.5** / 9.6	7.5 / **13.3** / 22.1	9 / **16** / 26
Nebraska	765	1.2 / **5.3** / 11.4	5.1 / **6.1** / 7.9	6.3 / **11.4** / 19.4	8 / **15** / 25
Georgia	699	1.1 / **4.8** / 10.5	5.6 / **6.8** / 8.7	6.7 / **11.6** / 19.2	10 / **17** / 27
Indiana	600	0.9 / **4.2** / 9.0	4.6 / **5.6** / 7.2	5.6 / **9.7** / 16.1	9 / **16** / 27
Oklahoma	570	0.9 / **4.0** / 8.5	3.8 / **4.6** / 5.9	4.7 / **8.5** / 14.4	8 / **15** / 25
Washington	527	0.8 / **3.7** / 7.9	44.3 / **53.2** / 68.5	45.1 / **56.8** / 76.4	86 / **108** / 145
Illinois	489	0.8 / **3.4** / 7.3	3.8 / **4.5** / 5.8	4.5 / **7.9** / 13.1	9 / **16** / 27
North Carolina	406	0.6 / **2.8** / 6.1	4.0 / **4.8** / 6.2	4.6 / **7.6** / 12.2	11 / **19** / 30
Nevada	375	0.6 / **2.6** / 5.6	1.2 / **1.4** / 1.8	1.8 / **4.0** / 7.4	5 / **11** / 20
Wyoming	322	0.5 / **2.2** / 4.8	3.5 / **4.1** / 5.3	4.0 / **6.4** / 10.2	12 / **20** / 32

Table S3: Top 15 states ranked by installed hyperscale capacity. Scenario intervals are efficiency / baseline / high-load.

BA	MW	Scope 1 (GL/yr)	Scope 2 (GL/yr)	Total (GL/yr)	Total (ML/MW-yr)
PJM	7,999	12.6 / **55.5** / 119.6	61.7 / **74.0** / 95.3	74.2 / **129.5** / 215.0	9 / **16** / 27
MISO	2,116	3.3 / **14.7** / 31.7	14.5 / **17.4** / 22.4	17.8 / **32.1** / 54.1	8 / **15** / 26
SPP	1,555	2.4 / **10.8** / 23.3	10.4 / **12.5** / 16.1	12.8 / **23.3** / 39.3	8 / **15** / 25
PACW	1,220	1.9 / **8.5** / 18.2	40.0 / **48.0** / 61.8	41.9 / **56.5** / 80.1	34 / **46** / 66
BPA	1,214	1.9 / **8.4** / 18.2	69.9 / **83.9** / 108.0	71.8 / **92.3** / 126.2	59 / **76** / 104
ERCOT	1,193	1.9 / **8.3** / 17.8	4.8 / **5.7** / 7.4	6.7 / **14.0** / 25.2	6 / **12** / 21
SOCO	699	1.1 / **4.8** / 10.5	5.6 / **6.8** / 8.7	6.7 / **11.6** / 19.2	10 / **17** / 27
TVA	480	0.8 / **3.3** / 7.2	7.5 / **9.0** / 11.5	8.2 / **12.3** / 18.7	17 / **26** / 39
SRP	460	0.7 / **3.2** / 6.9	3.9 / **4.7** / 6.1	4.6 / **7.9** / 12.9	10 / **17** / 28
DUK	406	0.6 / **2.8** / 6.1	4.0 / **4.8** / 6.2	4.6 / **7.6** / 12.2	11 / **19** / 30
AZPS	375	0.6 / **2.6** / 5.6	2.3 / **2.8** / 3.6	2.9 / **5.4** / 9.2	8 / **14** / 24
NEVP	375	0.6 / **2.6** / 5.6	1.2 / **1.4** / 1.8	1.8 / **4.0** / 7.4	5 / **11** / 20
GCPD	358	0.6 / **2.5** / 5.4	31.0 / **37.3** / 48.0	31.6 / **39.7** / 53.3	88 / **111** / 149
WACM	322	0.5 / **2.2** / 4.8	3.5 / **4.1** / 5.3	4.0 / **6.4** / 10.2	12 / **20** / 32
SCEG	310	0.5 / **2.2** / 4.6	2.5 / **3.0** / 3.8	3.0 / **5.1** / 8.5	10 / **17** / 27

Table S4: Top 15 balancing authorities ranked by installed hyperscale capacity. Scenario intervals are efficiency / baseline / high-load.

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