ANALYSIS & BRIEF

Johns Hopkins University · Ralph O'Connor Sustainable Energy Institute

# Data Center Flexibility and Grid Infrastructure Needs in PJM:

## Data Center Flexibility Policies Can Substantially Reduce Energy Infrastructure Investments Necessary to Keep the PJM Grid Reliable.

For questions, please reach out to Dr. Yury Dvorkin (ydvorki1@jhu.edu) or Abraham Silverman, J.D. (asilve39@jhu.edu) — March 2026

KEY FINDING


## Abstract

Data centers are the fastest-growing load in PJM, with 8.8 GW already under construction and between 16.2 GW to 57.4 GW planned. Whether this load is integrated as *firm* or *non-firm* service is the dominant determinant of system cost — more consequential than resolving all interconnection queue uncertainty combined. Shifting data center load to non-firm service, for example, through PJM's "connect & manage" proposal, reduces total annual system costs by **\$15–16 B** per scenario, compared to only \$4.2 B from successfully interconnecting all new generation currently in the generation queue. Under full firm service, annual operations costs exceed **\$66 B** across all three interconnection scenarios, reflecting a binding generation shortage that additional queue capacity cannot resolve. Non-firm service eliminates this constraint by substituting curtailment for capital investment in new generation, with firm load shedding remaining zero in every scenario examined. Non-firm curtailment of approximately **9.7 M MWh/yr** at full non-firm share is identical across all interconnection scenarios, confirming that curtailment risk is determined by service structure, not generation adequacy. Non-firm interconnection requirements for data centers are therefore the **single most effective tool** available to grid planners for containing infrastructure costs while preserving reliability.


## 1. Background

Data centers represent the fastest-growing load segment in PJM. All planned data center capacity totals up to **57.4 GW** across PJM zones[1], with an additional **8.8 GW** already in construction. How this load is integrated — as *firm* or *non-firm* load — and how much of it actually realizes will shape grid reliability, operating and investment costs, and the composition of generation and transmission expansion.

To assess the impact of various firm and non-firm service proposals under consideration at PJM, including PJM's "connect & manage" proposal, we employ a deterministic capacity expansion model (CEM) using the ICARUS dataset, which provides both PJM grid topology and data center pipeline data, to examine data center integration targeting the year 2028. We consider two main dimensions. First, how much of the planned data center pipeline actually materializes and what generation capacity queued for interconnection in PJM gets built. The second dimension is what share of that load is served on a non-firm basis — where curtailment is permitted — versus a firm basis, where supply must be guaranteed at all times. We define the following scenarios across these two dimensions:

- **Data center scenarios** — We use the PJM load forecast to model data center deployment by the target year of 2028. This modeling brings the total Data Center Demand (DC Demand) in PJM in 2028 to 16.2 GW and the non-coincidental peak demand to 172.2 GW.
- **Non-firm service share** — what fraction of that Data Center Demand (DC Demand) accepts curtailment rather than requiring guaranteed supply (non-firm share $\alpha \in \{0.0, 0.25, 0.50, 0.75, 1.0\}$), where:

$$\text{Firm Service} = \text{Base} + (1-\alpha)\cdot \text{DC Demand}$$
$$\text{Non-Firm Service} = \alpha \cdot \text{DC Demand}$$

**Model setup**: Our set up includes the ICARUS PJM and Data Center dataset, 4 representative seasons and 1 extreme season, 2028 transmission baseline, state-level RPS and technology carve-out constraints. For each generation candidate resource, we model the capacity available in PJM's interconnection queue, which is constrained by carve-outs for solar and storage technologies, and the least-cost, deterministic CEM model picks

[1] The data center load projections used in this study are provided by the ICARUS dataset, which maps data center growth from the U.S. DOE NLR "Speed to Power" dataset onto the PJM grid and is calibrated to PJM's load forecast. We adopt the classifications of "planned" and "in construction" data centers as defined in the U.S. DOE NLR "Speed to Power" dataset.

the optimal resource combination to serve the load forecast. For the generation queue, we model three scenarios — low, medium, and high — for new capacity entering service. The first scenario is the "2028 In-Service", which includes the resources with clearly stated deployment by 2028 or earlier (PJM characterizes these resources as "Active," "Engineering and Procurement" and "Under Construction"); the total includes 1.8 GW of solar and 0.4 GW of storage. The second scenario named "2028 + Unknown In-Service" includes all the generation in the previous scenario plus the projects with the unknown in-service dates that may not materialize on time. This second scenario includes 22.2 GW of natural gas, 20.3 GW of solar power, 0.6 GW of wind power, and 12.1 GW of storage. The third scenario named "TC1, TC2" includes all includes all the generation in the second scenario plus all generation scheduled to come online after 2028. The last scenario includes 22.8 GW of natural gas, 28.3 GW of solar power, 4.5 GW of wind power (including 2.5 GW of offshore wind power), and 14.9 GW of storage. We also note that the interconnection queue is an estimate of potential project additions. Historically, PJM has seen less than 20 percent of projects entering the queue actually coming online. Consistent with the U.S. EPA's Power Sector Modeling, we use the following notations for the PJM model regions and zones (See Table 1). This range of interconnection scenarios represent the range of optimistic ("TC1, TC2") and pessimistic ("2028 In-Service") scenarios on generation availability.

Table 1: Mapping between PJM model regions and zones (Source: PJM).

| Region | PJM zones |
|---|---|
| West | AEP, DAY, DLCO, DEOK, EKPC, OVEC |
| WMAC | METED, PPL |
| PENE | PENELEC |
| EMAC | PSEG, JCPL, AE, RECO, PECO, DPL |
| SMAC | BGE, PEPCO |
| APS | AP |
| ATSI | ATSI |
| COMD | ComEd |
| Dom | Dominion |

## 2. System Cost Impacts

### Non-Firm Share Is the Primary Cost Driver

Across all three interconnection scenarios, the non-firm share of data center load ($\alpha$) is the dominant lever for reducing total system cost (operations + investment + policy costs) — more powerful than expanding the interconnection queue itself. Moving from zero to full non-firm share reduces total system cost by roughly **\$15–16 B** annually within each scenario, compared to savings of only **\$4.2 B** from moving across the full range of interconnection scenarios at a fixed non-firm share (Table 2). Put differently, requiring all data centers to accept curtailment saves more than three times as much as resolving every interconnection queue uncertainty simultaneously.

Table 2: Key outcomes across interconnection scenarios and non-firm share values ($\alpha$) at full data center realization. Columns show results at 0% and 100% non-firm share for each scenario. See appendix for results at 25%, 50% and 75% non-firm share. (*Notes:* Investment costs reported as upfront values. All other costs annualized.)

| Metric | S1: 2028 | | S2: +Unk. | | S3: TC1,2 | |
|---|---|---|---|---|---|---|
| | 0% | 100% | 0% | 100% | 0% | 100% |
| **System Costs** | | | | | | |
| Total System Cost (\$B) | 76.28 | 60.93 | 73.18 | 58.27 | 72.05 | 57.34 |
| Total Investment Cost (\$B) | 3.90 | 4.11 | 22.97 | 21.33 | 34.99 | 33.35 |
| Generation (\$B) | 1.46 | 1.46 | 17.91 | 16.08 | 29.26 | 27.55 |
| Transmission (\$B) | 2.04 | 2.25 | 2.04 | 2.24 | 2.17 | 2.23 |
| Storage (\$B) | 0.40 | 0.40 | 3.02 | 3.02 | 3.57 | 3.57 |
| Operations Cost (\$B) | 73.27 | 57.94 | 69.01 | 54.29 | 66.82 | 52.29 |
| Non-compliance Cost (\$B) | 2.62 | 2.58 | 1.87 | 1.85 | 1.73 | 1.71 |
| **Reliability** | | | | | | |
| Firm Load Shed (MWh) | — | — | — | — | — | — |
| Non-Firm Curtail. (MWh) | — | 9.7M | — | 9.7M | — | 9.7M |

Not only do non-firm service options decrease total system costs, but it also changes the nature of investments in the grid, shifting investment away from higher operating costs, which includes production and penalty costs, towards capital investment in new infrastructure. Under full firm service ($\alpha$=0%), total system costs (Figure 1) remain prohibitively high across all interconnection scenarios — **\$76.3 B**, **\$73.2 B**, and **\$72.1 B** for Scenarios 1 through 3, respectively — with the narrow \$4.2 B spread across the full range of queue assumptions indicating that generation availability is a binding constraint under firm service. Scenario 1, which reflects only the 1.8 GW of solar and 0.4 GW of stor-

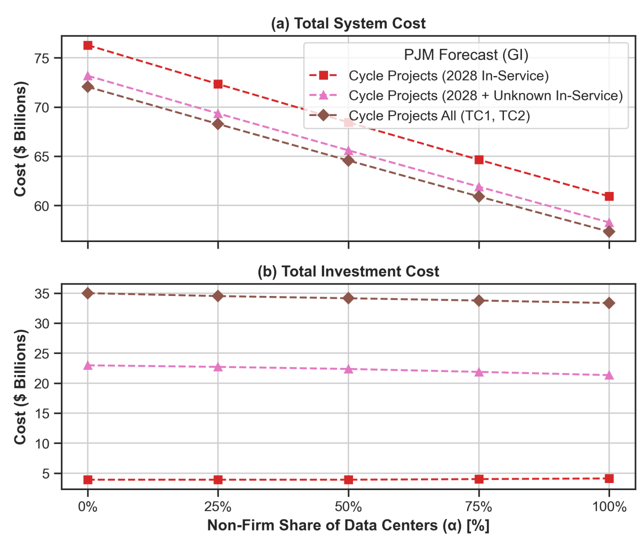



Figure 1: Total system cost (operations + investment) across interconnection scenarios and non-firm share values ($\alpha$).

age with confirmed 2028 in-service dates, is particularly acute: the absence of new dispatchable capacity forces near-total reliance on existing higher-cost units, producing \$73.3 B in annual operations cost. At full non-firm share ($\alpha$=100%), costs decline to \$60.9 B, \$58.3 B, and \$57.3 B, depending on which interconnection scenario we use - reductions achieved through curtailment rather than capacity adequacy.

### Effect of the Forecast Uncertainty on the Demand Center Forecast

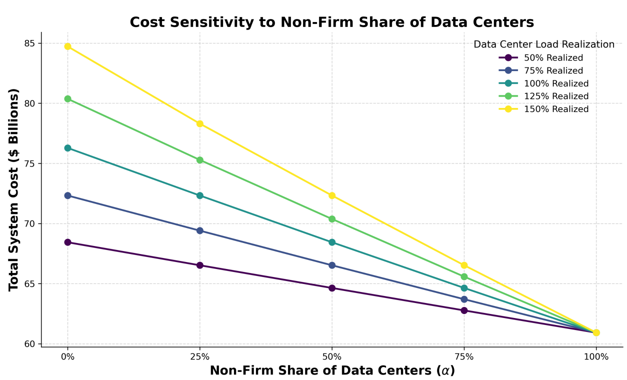
We analyze the effect of two primary uncertainty factors on total system cost: uncertainty in data center demand forecasts and uncertainty in the realization of projects from the generation interconnection queue. In both cases we stress-test either the data center demand or generation availability in the interconnection queue relative to the base case considered in Figure 1.

Total system cost is sensitive to the data center demand realized (Figure 2), which is particularly pronounced for the case where all data centers are on firm service, and the difference in total system cost reaches \$18B (Scenario 1) and \$16B (Scenario 3). We also note the ≈\$2B gap in the non-firm case due to the different assumptions on the generation queue availability. As the share of non-firm service increases, so does the total system cost. Notably, for the case with all data centers on non-firm service, the generation interconnection queue scenarios converge.

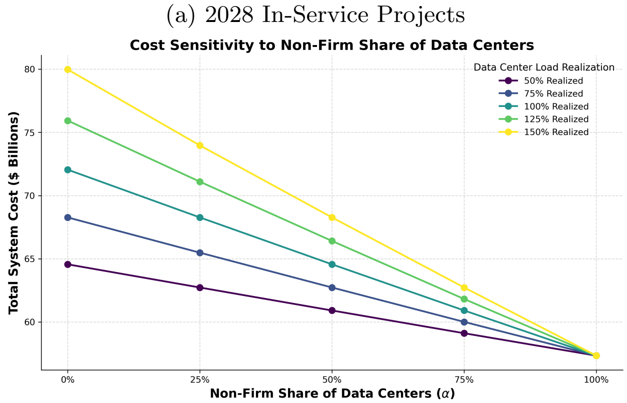
Figure 2 also displays the sensitivity of total cost across a range of project realization levels from the queue, considering two extreme generation interconnection queue outcomes represented by Scenario 1 and Scenario 3. We observe that, under both scenarios, the share of non-firm service linearly reduces system cost. The impact of project realizations from the queue is negligible in Scenario 1 (due to relatively limited generation capacity available for interconnection) and consistently reaches up to \$2.5B in Scenario 3.

### Investment vs. Operations: A Structural Tradeoff

The three scenarios differ fundamentally in *how* they achieve cost reductions, not merely in their magnitudes. Generation investment accounts for the vast majority of this divergence (Figure 3). In Scenario 1, generation investment is fixed at \$1.5 B regardless of $\alpha$, because there is simply no new generation available to build. Scenario 1 enters the model with almost no new generation to build — only 1.8 GW of confirmed solar and 0.4 GW of storage — and therefore relies almost entirely on existing capacity. The result is **very low investment cost** (\$3.9 B at $\alpha$=0%) but **very high annual operations cost** (\$73.3 B), as the system dispatches existing, higher-cost units to serve all firm load. Scenarios 2 and 3, with substantially greater but even more uncertain generation queues, build more capacity upfront — \$23.0 B and \$35.0 B in investment at $\alpha$=0%, respectively — and recover those costs through lower operations expenditure (\$69.0 B and \$66.8 B). This investment–operations substitution is the central structural difference across scenarios: **more available generation shifts costs from operations to capital**, while the total system cost remains within a relatively narrow \$4 B band.




(a) 2028 In-Service Projects




(b) All Cycle Projects (TC1, TC2)

Figure 2: Total system cost across varying data center load realizations under different interconnection scenarios and non-firm share values ($\alpha$).

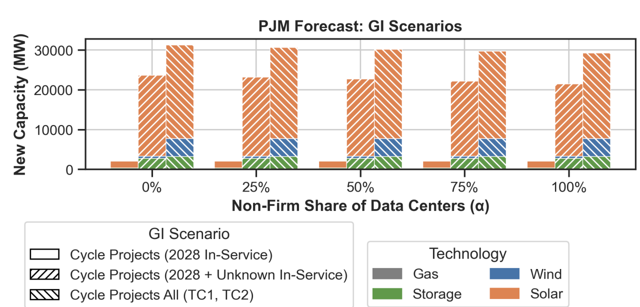



Figure 3: Generation and storage capacity expansion across interconnection scenarios and non-firm share values ($\alpha$).

Generation investment accounts for the vast majority of this divergence. In Scenario 1, generation investment is fixed at \$1.5 B regardless of $\alpha$, because there is simply no new generation available to build. In Scenario 2, it ranges from \$17.9 B at $\alpha$=0% down to \$16.1 B at $\alpha$=100%. In Scenario 3, it ranges from \$29.3 B to \$27.6 B over the same range. The modest decline with rising non-firm share (\$1.7–1.8 B across Scenarios 2 and 3) reflects the reduced need for peaking capacity when curtailable load can absorb demand spikes.

### Transmission and Storage

Transmission investment is remarkably stable across all three generation interconnection scenarios and non-firm shares, ranging from \$2.04 B to \$2.25 B (Figure 4). This stability suggests that the baseline transmission corridors identified by the model represent in part structural grid needs, i.e., these needs must be procured regardless of the data center growth or its uncertainty and regardless the generation queue assumptions. These are investments that *must* be made regardless of how uncertainty is resolved.

Comparing Figure 5a and Figure 5b, the only meaningful difference in specific transmission needs involves the Dom-SMAC corridor. This corridor is driven by additional generation deployment in Scenarios 2 and 3, which requires greater power transfer capacity, and becomes especially prominent at high non-firm demand fractions. Notably, this finding cuts both ways: non-firm service of data center demand in that region could *eliminate* the need for that particular transmission expansion.

Storage investment equally does not change (Figure 3), fixed at \$0.4 B in Scenario 1 and \$3.0–3.6 B in Scenarios 2 and 3 regardless of $\alpha$. This confirms that battery capacity is valued independently of whether data center load is served on a firm or non-firm basis.

### Non-Compliance Costs

Non-compliance costs — the sum of RPS shortfall penalties and technology carve-out violations — decline

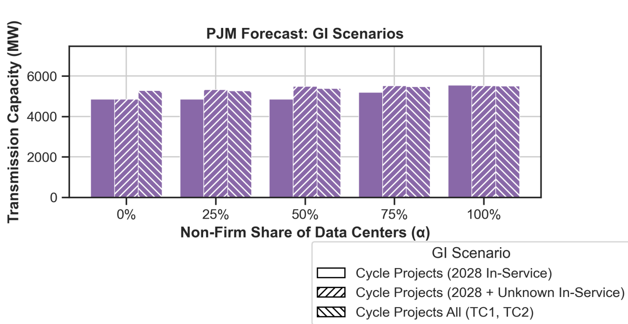
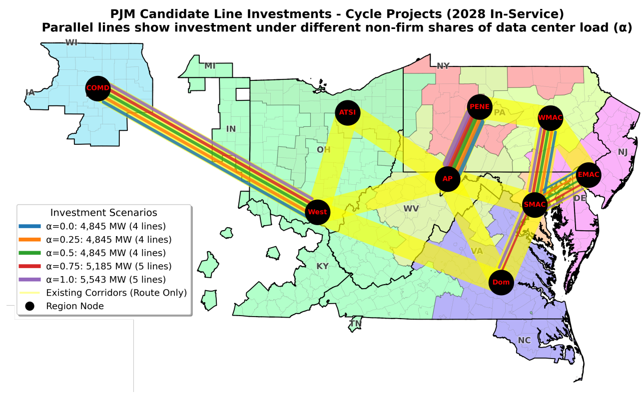
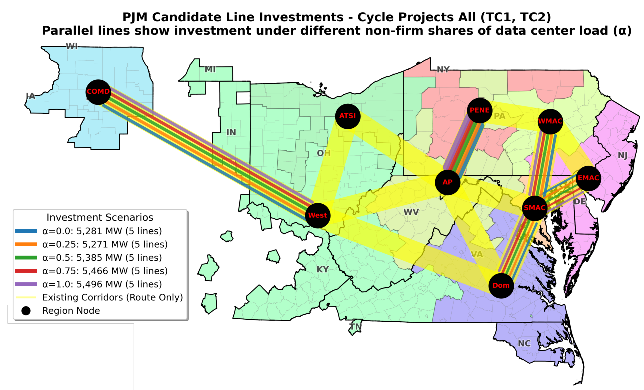



Figure 4: Transmission capacity expansion across interconnection scenarios and non-firm share values ($\alpha$).




(a) Scenario 1 for the generation interconnection.




(b) Scenario 2 and 3 for the generation interconnection..

Figure 5: Transmission expansion needs across all scenarios and non-firm demand shares for (a) Scenario 1 and (b) Scenarios 2 and 3. Investment totals are stable across both cases; the primary difference is the Dom-SMAC corridor, which appears under higher generation deployment and large non-firm demand fractions.

modestly as $\alpha$ increases, from \$2.62 B to \$2.58 B in Scenario 1, \$1.87 B to \$1.85 B in Scenario 2, and \$1.73 B to \$1.71 B in Scenario 3. The improvement with higher non-firm share reflects reduced reliance on gas dispatch rather than any increase in renewable build-out. More notably, non-compliance costs fall substantially *across* scenarios as the interconnection queue expands, from \$2.6 B in Scenario 1 to \$1.7 B in Scenario 3, because of greater generation interconnection queues that bring the system closer to meeting renewable carve-out targets. Strict RPS compliance remains uneconomic under current cost assumptions in all scenarios; the penalty is best understood as a proxy for REC procurement costs rather than a binding policy constraint.

## 3. Grid Reliability Implications

A critical finding is the **absence of firm load shedding** across all 25 scenarios under the least-cost, deterministic CEM. This holds across every combination of interconnection scenario and non-firm service share examined — from Scenario 1, which reflects only confirmed 2028 in-service capacity, through Scenario 3, which includes the full TC1/TC2 generation queue. This result is a direct consequence of a relatively high value of lost load (VoLL) of $2,000/MWh, making involuntary curtailment of firm demand prohibitively expensive relative to capacity investment. A second driver is the enforcement of RPS and technology carve-outs, which force a minimum deployment of renewables and batteries across all scenarios and structurally improve system adequacy independent of the interconnection queue assumption.

Non-firm curtailment scales predictably with the non-firm service share ($\alpha$) and is essentially identical across all three interconnection scenarios. At $\alpha$=0% (full firm service), non-firm curtailment is zero throughout — consistent with a system designed to guarantee supply to all load at all times. At $\alpha$=100% (full non-firm service), curtailment reaches approximately 9.7 M MWh in all three scenarios: 9.74 M MWh in Scenario 1 and 9.73 M MWh in Scenarios 2 and 3. The near-identical curtailment profiles across scenarios — despite investment levels ranging from $3.9 B in Scenario 1 to $35.0 B in Scenario 3 — confirm that non-firm curtailment is determined by the contracted service structure rather than generation adequacy. This curtailment is priced at $0/MWh, reflecting its contractual nature, and represents the primary mechanism by which the system avoids costly capacity investment at high non-firm service shares.

**RPS non-compliance** persists across all scenarios and non-firm service shares. In Scenario 1, non-compliance ranges from 3.73 M MWh at $\alpha$=0% to 3.58 M MWh at $\alpha$=100%. Scenarios 2 and 3 are identical on this metric, declining from 3.65 M MWh to 3.50 M MWh over the same range — somewhat lower than Scenario 1, reflecting the larger renewable buildout in those interconnection queues. Within each scenario, the modest decline with rising non-firm share reflects reduced reliance on gas dispatch rather than any increase in renewable build-out relative to the RPS target. Strict RPS compliance remains uneconomic under current cost assumptions in all scenarios; the non-compliance penalty is best understood as a proxy for REC procurement costs rather than a binding policy constraint.

Carve-out non-compliance differs across interconnection scenarios but is invariant to the non-firm service share within each. Scenario 1 carries the largest shortfall at 8,411 MW, a direct consequence of its minimal storage buildout of only 366 MW under the constrained 2028 in-service queue. Scenario 2 reduces this to 5,782 MW through a substantially larger storage deployment of 2,743 MW enabled by the expanded interconnection queue, and Scenario 3 achieves the lowest non-compliance at 5,282 MW with 3,243 MW of storage added. In all cases the carve-out constraint remains binding, indicating that fully closing the gap would require storage investment levels the model currently deems uneconomic under present cost assumptions.

## 4. Policy Implications

### For Grid Planners & PJM

- Non-firm interconnection requirements for data centers, such as PJM's pending Connect & Manage rules, are the **single most effective tool** available for containing infrastructure costs. Shifting all data center load to non-firm service reduces total system costs by **$15–16 B** annually per scenario — more than three times the savings achievable by resolving all interconnection queue uncertainty simultaneously.
- Under full firm service, the grid faces a **binding generation shortage** regardless of which interconnection scenario materializes, with annual operations costs exceeding **$66 B** across all three cases. Non-firm service eliminates this constraint by substituting curtailment for capital investment.
- Transmission investment is structurally stable at **$2.0–2.3 B** regardless of interconnection scenario or non-firm share, indicating a baseline of grid upgrades that must proceed independent of demand uncertainty. The Dom–SMAC corridor is the only exception, and non-firm service of Dominion-area data center load could *eliminate* the need for that expansion entirely.
- Battery storage deployment ($0.4–3.6 B depending on queue scenario) does not change with non-firm share, confirming that storage carve-out policy is effective and should be maintained.

### For Policymakers

- Regulation enabling non-firm data center service tariffs — including PJM's "connect and manage" curtailment proposal and FERC's non-firm transmission service proposal — could reduce total annualized system costs by **up to 20%** and substantially limit exposure to ratepayer cost increases.
- Non-firm requirements serve as an **effective hedge against demand forecast uncertainty**: because curtailment substitutes for capacity investment across a wide range of data center realization levels, the policy remains cost-effective even if the full planned capacity does not materialize.

### For Data Center Operators

- Non-firm service (with associated curtailment of approximately **9.7 M MWh/yr** at full non-firm share) substantially lowers system-wide cost implications and may translate to lower interconnection costs. Critically, curtailment volume is *identical* across all three interconnection scenarios, indicating that curtailment risk is determined by service structure, not generation adequacy.

- Operators with deferrable workloads — AI model training, batch inference, data backup, and archival compute — are best positioned to absorb non-firm curtailment risk and benefit from associated tariff reductions.

## 5. Conclusion

Non-firm data center service is the dominant cost lever in PJM, reducing total annual system costs by \$15–16,B per scenario — more than three times the savings from resolving all interconnection queue uncertainty combined, with firm load shedding zero in every case. Non-firm service shifts costs structurally: investment rises modestly while operations costs fall sharply, replacing expensive dispatch with upfront capital. These results are sensitive to interconnection queue acceleration and data center efficiency improvements, both of which could materially alter cost outcomes. How much flexibility the data center fleet can actually provide in practice remains an open and critical research question for grid planners and policymakers alike.

## 6. Appendix: Full Results by Scenario and Non-Firm Share

The following tables report complete results for all three interconnection scenarios across the full range of non-firm service share values ($\alpha \in \{0\%, 25\%, 50\%, 75\%, 100\%\}$). Each table covers system costs, reliability outcomes, and capacity additions for generation, transmission, and storage. Results are presented for the base data center demand realization of 16.2 GW, consistent with the PJM load forecast used throughout the analysis. Metrics are reported as annualized costs except investment costs, which are reported as upfront capital values.

### Scenario 1: 2028 In-Service

Table 3: Full results for Scenario 1 (2028 In-Service) across all non-firm share values ($\alpha$). (*Notes:* Investment costs reported as upfront values. All other costs annualized.)

| Metric | 0% | 25% | 50% | 75% | 100% |
|---|---|---|---|---|---|
| **System Costs** | | | | | |
| Total System Cost ($B) | 76.28 | 72.33 | 68.44 | 64.64 | 60.93 |
| Total Investment Cost ($B) | 3.90 | 3.90 | 3.90 | 4.00 | 4.11 |
| Generation Inv. Cost ($B) | 1.46 | 1.46 | 1.46 | 1.46 | 1.46 |
| Transmission Inv. Cost ($B) | 2.04 | 2.04 | 2.04 | 2.14 | 2.25 |
| Storage Inv. Cost ($B) | 0.40 | 0.40 | 0.40 | 0.40 | 0.40 |
| Operations Cost ($B) | 73.27 | 69.33 | 65.45 | 61.65 | 57.94 |
| RPS Non-compliance Cost ($B) | 0.41 | 0.40 | 0.39 | 0.38 | 0.37 |
| Carve-out Non-comp. Cost ($B) | 2.21 | 2.21 | 2.21 | 2.21 | 2.21 |
| **Reliability** | | | | | |
| Firm Load Shed (MWh) | — | — | — | — | — |
| Non-Firm Curtailment (MWh) | — | 2.44M | 4.87M | 7.31M | 9.74M |
| RPS Non-Compliance (MWh) | 3.73M | 3.69M | 3.65M | 3.62M | 3.58M |
| Carve-out Non-Compliance (MW) | 8,411 | 8,411 | 8,411 | 8,411 | 8,411 |
| **Generation Capacity Added (GW)** | | | | | |
| Total Solar | 1.72 | 1.72 | 1.72 | 1.72 | 1.72 |
| ATSI | 0.06 | 0.06 | 0.06 | 0.06 | 0.06 |
| COMD | 0.89 | 0.89 | 0.89 | 0.89 | 0.89 |
| Dom | 0.19 | 0.19 | 0.19 | 0.19 | 0.19 |
| PENE | 0.02 | 0.02 | 0.02 | 0.02 | 0.02 |
| West | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |
| Total Wind | — | — | — | — | — |
| Total Gas | — | — | — | — | — |
| **Transmission Capacity Added (MW)** | | | | | |
| Total | 4,845 | 4,845 | 4,845 | 5,185 | 5,543 |
| Line 14 (EMAC–SMAC) | 300 | 300 | 300 | 300 | 300 |
| Line 15 (SMAC–WMAC) | 780 | 780 | 780 | 780 | 780 |
| Line 16 (COMD–West) | 980 | 980 | 980 | 980 | 980 |
| Line 18 (Dom–SMAC) | — | — | — | 340 | 698 |
| Line 20 (AP–PENE) | 2,785 | 2,785 | 2,785 | 2,785 | 2,785 |
| **Storage Capacity Added (MW)** | | | | | |
| Total | 366 | 366 | 366 | 366 | 366 |
| Battery (EMAC) | 70 | 70 | 70 | 70 | 70 |
| Battery (West) | 296 | 296 | 296 | 296 | 296 |

### Scenario 2: 2028 + Unknown In-Service

Table 4: Full results for Scenario 2 (2028 + Unknown In-Service) across all non-firm share values ($\alpha$). (*Notes:* Investment costs reported as upfront values. All other costs annualized.)

| Metric | 0% | 25% | 50% | 75% | 100% |
|---|---|---|---|---|---|
| **System Costs** | | | | | |
| Total System Cost ($B) | 73.18 | 69.35 | 65.60 | 61.91 | 58.27 |
| Total Investment Cost ($B) | 22.97 | 22.71 | 22.36 | 21.87 | 21.33 |
| Generation Inv. Cost ($B) | 17.91 | 17.51 | 17.11 | 16.62 | 16.08 |
| Transmission Inv. Cost ($B) | 2.04 | 2.18 | 2.23 | 2.24 | 2.24 |
| Storage Inv. Cost ($B) | 3.02 | 3.02 | 3.02 | 3.02 | 3.02 |
| Operations Cost ($B) | 69.01 | 65.21 | 61.51 | 57.87 | 54.29 |
| RPS Non-compliance Cost ($B) | 0.35 | 0.34 | 0.34 | 0.33 | 0.33 |
| Carve-out Non-comp. Cost ($B) | 1.52 | 1.52 | 1.52 | 1.52 | 1.52 |
| **Reliability** | | | | | |
| Firm Load Shed (MWh) | — | — | — | — | — |
| Non-Firm Curtailment (MWh) | — | 2.43M | 4.86M | 7.29M | 9.73M |
| RPS Non-Compliance (MWh) | 3.65M | 3.61M | 3.57M | 3.53M | 3.50M |
| Carve-out Non-Compliance (MW) | 5,782 | 5,782 | 5,782 | 5,782 | 5,782 |
| **Generation Capacity Added (GW)** | | | | | |
| Total Solar | 20.34 | 19.87 | 19.40 | 18.82 | 18.19 |
| AP | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 |
| ATSI | 0.41 | 0.41 | 0.41 | 0.41 | 0.41 |
| COMD | 5.42 | 4.95 | 4.49 | 3.91 | 3.27 |
| Dom | 4.90 | 4.90 | 4.90 | 4.90 | 4.90 |
| EMAC | 0.47 | 0.47 | 0.47 | 0.47 | 0.47 |
| PENE | 0.37 | 0.37 | 0.37 | 0.37 | 0.37 |
| SMAC | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| WMAC | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| West | 7.78 | 7.78 | 7.78 | 7.78 | 7.78 |
| Total Wind | 0.58 | 0.58 | 0.58 | 0.58 | 0.58 |
| AP | 0.47 | 0.47 | 0.47 | 0.47 | 0.47 |
| PENE | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 |
| Total Gas | — | — | — | — | — |
| **Transmission Capacity Added (MW)** | | | | | |
| Total | 4,845 | 5,318 | 5,490 | 5,511 | 5,510 |
| Line 14 (EMAC–SMAC) | 300 | 300 | 300 | 300 | 300 |
| Line 15 (SMAC–WMAC) | 780 | 780 | 780 | 780 | 780 |
| Line 16 (COMD–West) | 980 | 980 | 980 | 980 | 980 |
| Line 18 (Dom–SMAC) | — | 473 | 645 | 666 | 665 |
| Line 20 (AP–PENE) | 2,785 | 2,785 | 2,785 | 2,785 | 2,785 |
| **Storage Capacity Added (MW)** | | | | | |
| Total | 2,743 | 2,743 | 2,743 | 2,743 | 2,743 |
| Battery (AP) | 195 | 195 | 195 | 195 | 195 |
| Battery (Dom) | 1,141 | 1,141 | 1,141 | 1,141 | 1,141 |
| Battery (EMAC) | 476 | 476 | 476 | 476 | 476 |
| Battery (SMAC) | 635 | 635 | 635 | 635 | 635 |
| Battery (West) | 296 | 296 | 296 | 296 | 296 |

### Scenario 3: TC1, TC2

Table 5: Full results for Scenario 3 (TC1, TC2) across all non-firm share values ($\alpha$). (*Notes:* Investment costs reported as upfront values. All other costs annualized.)

| Metric | 0% | 25% | 50% | 75% | 100% |
|---|---|---|---|---|---|
| **System Costs** | | | | | |
| Total System Cost ($B) | 72.05 | 68.27 | 64.56 | 60.91 | 57.34 |
| Total Investment Cost ($B) | 34.99 | 34.51 | 34.14 | 33.77 | 33.35 |
| Generation Inv. Cost ($B) | 29.26 | 28.77 | 28.37 | 27.98 | 27.55 |
| Transmission Inv. Cost ($B) | 2.17 | 2.16 | 2.20 | 2.22 | 2.23 |
| Storage Inv. Cost ($B) | 3.57 | 3.57 | 3.57 | 3.57 | 3.57 |
| Operations Cost ($B) | 66.82 | 63.10 | 59.43 | 55.82 | 52.29 |
| RPS Non-compliance Cost ($B) | 0.34 | 0.34 | 0.33 | 0.33 | 0.32 |
| Carve-out Non-comp. Cost ($B) | 1.39 | 1.39 | 1.39 | 1.39 | 1.39 |
| **Reliability** | | | | | |
| Firm Load Shed (MWh) | — | — | — | — | — |
| Non-Firm Curtailment (MWh) | — | 2.43M | 4.86M | 7.29M | 9.73M |
| RPS Non-Compliance (MWh) | 3.65M | 3.61M | 3.57M | 3.53M | 3.50M |
| Carve-out Non-Compliance (MW) | 5,282 | 5,282 | 5,282 | 5,282 | 5,282 |
| **Generation Capacity Added (GW)** | | | | | |
| Total Solar | 23.49 | 22.92 | 22.45 | 21.98 | 21.48 |
| AP | 0.65 | 0.65 | 0.65 | 0.65 | 0.65 |
| ATSI | 0.41 | 0.41 | 0.41 | 0.41 | 0.41 |
| COMD | 5.10 | 4.53 | 4.06 | 3.59 | 3.09 |
| Dom | 6.25 | 6.25 | 6.25 | 6.25 | 6.25 |
| EMAC | 0.47 | 0.47 | 0.47 | 0.47 | 0.47 |
| PENE | 0.77 | 0.77 | 0.77 | 0.77 | 0.77 |
| SMAC | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| WMAC | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| West | 9.50 | 9.50 | 9.50 | 9.50 | 9.50 |
| Total Wind | 4.51 | 4.51 | 4.51 | 4.51 | 4.51 |
| AP | 0.47 | 0.47 | 0.47 | 0.47 | 0.47 |
| COMD | 0.69 | 0.69 | 0.69 | 0.69 | 0.69 |
| Dom | 2.49 | 2.49 | 2.49 | 2.49 | 2.49 |
| PENE | 0.11 | 0.11 | 0.11 | 0.11 | 0.11 |
| West | 0.75 | 0.75 | 0.75 | 0.75 | 0.75 |
| Total Gas | — | — | — | — | — |
| **Transmission Capacity Added (MW)** | | | | | |
| Total | 5,281 | 5,271 | 5,385 | 5,466 | 5,496 |
| Line 14 (EMAC–SMAC) | 300 | 300 | 300 | 300 | 300 |
| Line 15 (SMAC–WMAC) | 780 | 780 | 780 | 780 | 780 |
| Line 16 (COMD–West) | 980 | 980 | 980 | 980 | 980 |
| Line 18 (Dom–SMAC) | 436 | 426 | 540 | 621 | 651 |
| Line 20 (AP–PENE) | 2,785 | 2,785 | 2,785 | 2,785 | 2,785 |
| **Storage Capacity Added (MW)** | | | | | |
| Total | 3,243 | 3,243 | 3,243 | 3,243 | 3,243 |
| Battery (AP) | 195 | 195 | 195 | 195 | 195 |
| Battery (Dom) | 1,141 | 1,141 | 1,141 | 1,141 | 1,141 |
| Battery (EMAC) | 476 | 476 | 476 | 476 | 476 |
| Battery (SMAC) | 1,135 | 1,135 | 1,135 | 1,135 | 1,135 |
| Battery (West) | 296 | 296 | 296 | 296 | 296 |