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Generator Interconnection Cost Analysis in the Southwest Power Pool (SPP) Territory

Network upgrade costs have risen, especially among projects that withdraw from the queue

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Executive summary

Interconnection queues have grown dramatically throughout the United States. In SPP, the cumulative capacity of projects actively seeking interconnection increased more than five-fold from 2013 through 2022. Based on evaluated data on project-level interconnection costs from SPP, our analysis finds:

- **Project-specific interconnection costs can differ widely** depending on many variables, and they do not have the shape of a normal distribution. For example, 92% of projects that have completed all required interconnection studies ("complete") between 2020 and 2022 have costs under $125/kW, but six projects cluster around $220/kW and one project has interconnection costs of $475/kW. At the same time, a third of this sample has costs under $15/kW. We give summary statistics throughout this briefing as simple means to judge macro-level trends.
- **Average interconnection costs are stable for projects that complete all interconnection studies but have escalated for those that withdraw**. Costs for recent "complete" projects (2020-2022: $57/kW) are largely unchanged from the 2000s (2002-2009: $54/kW), though they were slightly lower in the 2010s ($43/kW). Interconnection requests that withdraw from the queue ("withdrawn") saw large cost escalations in the 2010s (from $22/kW in the 2000s to $247/kW) and continued to climb in the early 2020s to $304/kW (medians: 2000s: $15/kW, 2010s: $168/kW, 2020-2022: $184/kW). Projects still working their way through the queue have average costs of $106/kW in 2020-2023 (median: $66/kW). Average costs for withdrawn projects are now five times the costs of complete projects, likely a key driver for those withdrawals. All costs are expressed in real $2022 terms based on a GDP deflator conversion.
- **Broader network upgrade costs are the primary driver of recent cost increases, especially for withdrawn projects.** Costs for local attachment facilities have historically dominated interconnection costs for generators in SPP, but these Point of Interconnection (POI) costs have recently fallen for complete projects (mean: $53/kW in 2000s to recent $34/kW, median: $24/kW and $15/kW). No costs for broader network upgrades beyond the interconnecting substation were reported in the 2000s, but they have recently increased on average to $23/kW in the 2020s (median: $2/kW). For withdrawn projects, these network costs grew strongly in the 2010s (mean: $180/kW, median: $104/kW) and continued to climb for some in the 2020s (mean: $230/kW, median: $61/kW). Recent active projects had intermediate costs for POI and network upgrades ($58/kW).
- **Potential interconnection costs of all solar ($157/kW) and wind ($154/kW) requests have been greater than those of storage ($109/kW) and natural gas ($97/kW) projects since 2010.** Among completed projects in our sample, recent interconnection costs for solar ($99/kW) and natural gas ($53/kW) have increased compared to historical costs (2010s), while wind costs have decreased ($43/kW). Solar projects that ultimately withdrew had interconnection costs of $394/kW (equivalent to 25% of total project installed costs), compared to $263/kW (or 17%) for withdrawn wind applicants.
- **Economies of scale exist for completed wind and solar projects but not for other fuel types or withdrawn projects.** Among complete wind projects, costs fall from $61/kW for medium-sized projects (20-100 MW) to $47/kW for large (100-250 MW) and $44/kW for very large (250-675 MW) projects. The size efficiencies generally hold for POI but not network costs in our sample. Costs for withdrawn projects do not demonstrate economies of scale.
- **Interconnection costs vary by location**, with projects in the northern part of SPP (South Dakota, Indiana, Montana) often reporting higher costs than in the south (Oklahoma, Arkansas, Missouri), but these regional trends are not very strong.

The cost sample analyzed here represents 845 projects requesting interconnection in SPP from 2001 to 2023, including all of the most refined cost estimates available. Interconnection cost data is difficult to obtain, posing an information barrier for prospective developers and resulting in a less efficient interconnection process. We have posted project-level cost data from this analysis at https://emp.lbl.gov/interconnection_costs.

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1. Interconnection queue capacity has grown more than five-fold since 2013

At year-end 2022, SPP had 109 gigawatts (GW) of generation and storage capacity actively seeking grid interconnection. Capacity in SPP's queue is almost entirely (>96%) clean energy, including solar and solar hybrids (51 GW), wind (35 GW), and standalone storage (13 GW). SPP's queue also contains data for projects no longer trying to interconnect, both those that are in service (38 GW) and those whose applications have been withdrawn (226 GW) (Rand et al. 2023). SPP's queue has ballooned over the past decade: the cumulative active queue is now more than five times larger than in 2013, with 2022 cluster additions being nearly three times the size of 2021 cluster requests (SPP 2023a). The capacity associated with interconnection requests is more than twice as large as SPP's peak load in recent years (~51 GW) and, if a substantial share is built, it will likely exert competitive pressure on existing generation. But historically, most projects withdraw: only 18% of projects (14% of capacity) requesting interconnection in SPP from 2000 to 2017 achieved commercial operation by year-end 2022. SPP itself anticipates significant near-term annual growth in new online resources from 2.9 GW in 2023 to 18.8 GW in 2025 (SPP 2023b).

Interconnection backlogs first emerged in SPP in the late 2000s, when a large volume of wind energy capacity sought interconnection (Rand et al. 2022). Accordingly, in 2009, SPP initiated a set of interconnection process reforms to transition from a serial, "first-come, first-served" model to a clustered, "first-ready, first-served" approach. These reforms were also designed to discourage speculative projects from staying in the queue by increasing deposits and requiring stricter project readiness criteria (FERC 2019). SPP followed this up with additional reforms introduced in 2013 to increase milestone requirements and financial deposits (FERC 2019). Despite these measures, active queue capacity surged by over 480% from 2014 to 2019, reaching over 90 GW in 2019 (over 99% of which was wind, solar, and battery capacity). Additional queue process reforms were introduced in 2019 to refine the three-stage study process and introduce financial deposit requirements at each stage (FERC 2019), and again in 2022 to establish more stringent site control, readiness, and financial requirements (SPP 2022). SPP plans to release an interactive tool that provides more information about available transmission capacity for prospective interconnection customers.

2. Sample represents all of the most refined cost estimates available

This brief analyzes generator interconnection cost data from 845 projects that were evaluated in interconnection studies between 2002 and 2023, equivalent to 47% of all interconnection requests entering the queue between 2001 and 2022 (Figure 1, left panel). While the sample allows for a detailed analysis of interconnection costs, it represents only a subset of the 1,803 projects that were listed in the queue as of March 2022. Our interconnection cost sample is based on many, but not all, of the 1,441 unique generator interconnection studies that were accessible in the online SPP system (many of which do not include cost data).[1] We reviewed 31 out of 204 feasibility cluster studies (containing 146 of 472 interconnection requests), the majority of which pertain to older projects that withdrew from the interconnection queue at this stage without having interconnection cost estimates yet. We obtained 85 final cost estimates from these feasibility studies. We reviewed roughly half of the available 664 impact studies of the 2016-and-earlier Definitive Interconnection System Impact Study (DISIS) cluster cohorts and found that only a very small subset of PDF files included cost estimates. SPP recently started publishing preliminary system impact study cost estimates in Excel format for more recent queue entrants. We reviewed all available cost data across seven studies for the DISIS cohorts 2017 to 2020 (posted between November 2021 and March 2023) describing 383 unique generators; and added cost estimates for 308 of those projects to our final sample. Several feasibility and system impact cost estimates were superseded by more refined facility studies, which

[1] Accessible here: https://opsportal.spp.org/Studies/Gen

became our main collection focus. Our team reviewed all of the 572 available facilities studies in PDF format (except when studies were superseded by an updated analysis) and gathered 453 final cost estimates from these studies. These data are the best available interconnection cost estimates in SPP's posted data, as the final generator interconnection agreements are not public. We were not able to analyze costs for projects entering the queue after December 2020, as insufficient time had elapsed for their associated interconnection studies and cost estimates to be posted online. We spent more than 400 hours assembling the cost sample. The lack of easily accessible refined interconnection cost data poses an information barrier for analysts and prospective developers, resulting in a less efficient interconnection process. We have posted project-level cost data from this analysis at https://emp.lbl.gov/interconnection_costs.

Interconnection Request Status Definitions

Complete: These projects have completed all interconnection studies and progressed to (or completed) the interconnection agreement phase. This includes plants that are now in service.

Active: These projects are actively working through the interconnection study process, progressing from an initial feasibility study to a system impact study and finally to a refined facility study. We do not report results explicitly for this request category due to a small sample size of only five projects.

Withdrawn: These interconnection requests have been withdrawn from the queue (cancelled).

The cost sample varies over time with respect to request status (Figure 1, right panel), which we updated based on interconnection queue information as of January 2023. Completed projects with a fully executed interconnection agreement were studied between 2003 and 2022 (262 projects, 45.7 GW). An additional 271 projects (49 GW) in our cost sample were still actively moving through the interconnection process as of January 2023. All of their system impact and facility studies were performed between 2021 and 2023, making up the majority of the most recent interconnection cost estimates. We have the most data for projects that ultimately withdrew from the interconnection process which were studied between 2002 and 2022 (312 projects, 57.2 GW).

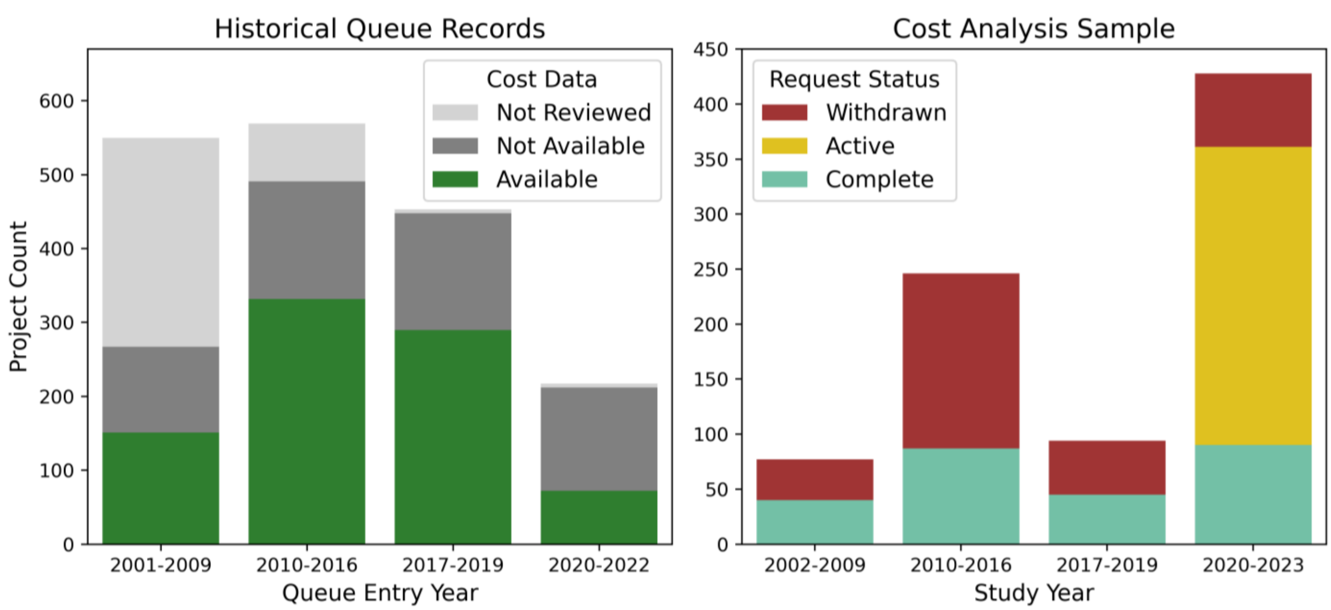

Figure 1. Availability of Sample Cost Data Relative to Historical Queue Records *(left)* **and Cost Data by Request Status** *(right). The left graph shows all historical generators seeking interconnection, indexed by their queue entry year. The right graph represents our cost analysis sample, with projects indexed by the year of the last available interconnection study. The remainder of this briefing will index projects by their study year.*

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3. Network upgrade expenses have grown in recent years

Interconnection cost data were collected manually from public interconnection study reports, using the most recent study type available. The interconnection cost data summarized here are based exclusively on cost estimates in interconnection study reports, and those costs are the responsibility of the interconnection customer (i.e., project developer). However, our estimates presented here do not include all interconnection-related expenses that may be borne by a project developer, such as the interconnection customer's interconnection facilities (i.e., equipment located between the generating facility and the point of change of ownership, such as transformation substations, step-up transformers, or spur lines), since those costs are not listed in the interconnection studies.

We assume the reported costs refer to nominal dollars at the time of the interconnection study, and present costs in real $2022 terms based on a GDP deflator conversion. We present interconnection costs in $/kW to facilitate comparisons, using the nameplate capacity of each project. We report simple means with standard errors throughout the briefing as detailed in the following textbox.

Interconnection Cost Metrics

The cost data do not have the shape of a normal distribution: many projects have rather low costs (or cost components), while a few projects have very high costs. We give summary statistics throughout this briefing as **simple means** to judge macro-level trends. Below is an example using completed project costs between 2020 and 2022. The histogram shows that more than 92% of all projects in this sample have interconnection costs under $125/kW, but six projects cluster around $220/kW, and one has costs of $475/kW (Figure 2, left). Medians (shown as dashed lines in the center of the boxplot) describe a "typical" project, with costs of $34/kW, but individual median cost components cannot be added to meaningful sums (Figure 2, middle). Means (Figure 2, right) can be influenced by a small number of projects with very high costs and are often higher than medians ($57/kW), but aggregated cost components can easily be added. We include the standard error of the mean ($\hat{\sigma}_{\bar{x}}$) as a measure of dispersion to give a sense of how scattered the data are. We point to median values in footnotes throughout the text.

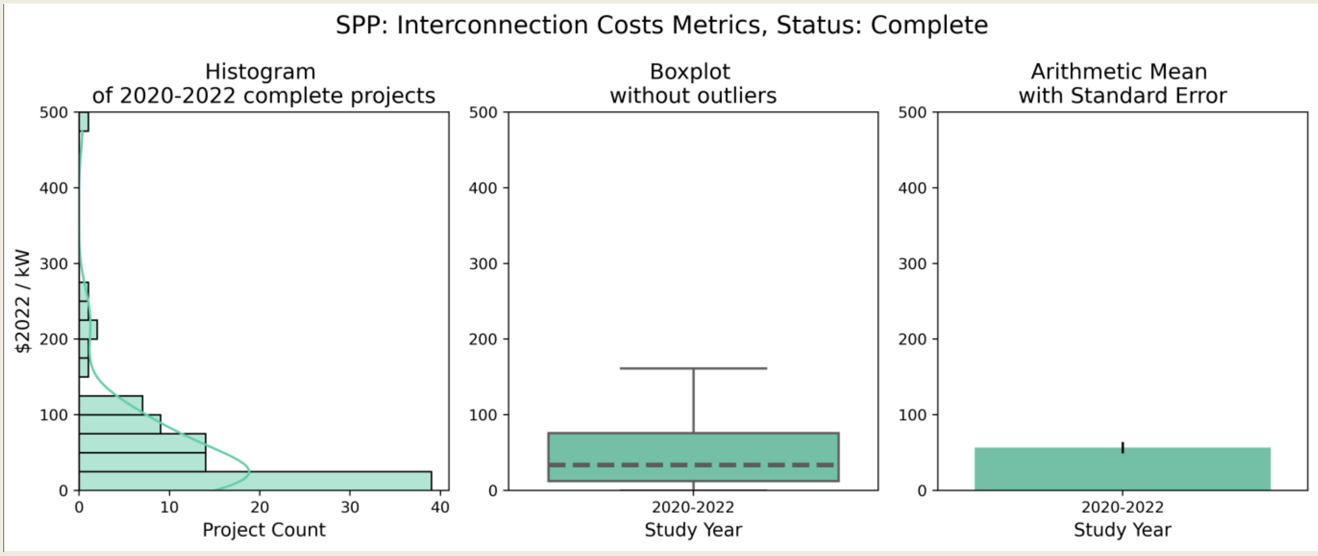

Figure 2. Interconnection Cost Metrics Example: Subsample of Projects Completing the Study Process, 2020-2022

The Appendix contains more information about the distribution of the cost data, showing box-plot versions of all graphs and illustrating the very wide spread in the underlying data from which the averages in this core briefing are derived.

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3.1 Average interconnection costs have grown for withdrawn projects

Average potential interconnection costs across all applicants in our sample quadrupled since 2002-2009. But combining all projects regardless of request status is problematic. Our cost sample composition changes over time, containing many withdrawn projects between 2010 and 2016, while the period between 2020 and 2023 is dominated by active projects (Figure 1, right panel). Focusing on any given study cohort, one would expect that average interconnection costs decline as projects proceed through the queue and high-cost projects naturally withdraw.

The trend of increasing interconnection costs is more nuanced when accounting for the request status of a project applicant (Figure 3). Among projects with completed interconnection studies, average sampled interconnection costs have been largely stable: they fall from \$54/kW (2002-2009) to \$43/kW (2010-2019) before increasing to \$57/kW between 2020 and 2022; the standard error of the mean ($\hat{\sigma}_{\bar{x}}$) is \$21/kW, \$4/kW, and \$7/kW, respectively.

Sampled projects that withdraw have seen very large cost escalations between 2002-2009 and 2010-2019, from \$22/kW to \$247/kW ($\hat{\sigma}_{\bar{x}}$= \$4/kW & \$19/kW), followed by a continued increase in costs over the most recent period between 2020 and 2022 to \$304/kW ($\hat{\sigma}_{\bar{x}}$=\$41/kW).[2] Although costs don't seem to have been a primary driver for project withdrawals in the early years (2002-2009), average costs for withdrawn projects are now five times the costs of "complete" projects between 2020 and 2022.

Interconnection costs for active projects in our sample are derived nearly exclusively from system impact studies and refer to projects that have not yet executed an interconnection agreement or withdrawn from the queue. They have costs of \$106/kW ($\hat{\sigma}_{\bar{x}}$=\$15/kW) – greater than the average complete project, but smaller than the average withdrawn project.[3]

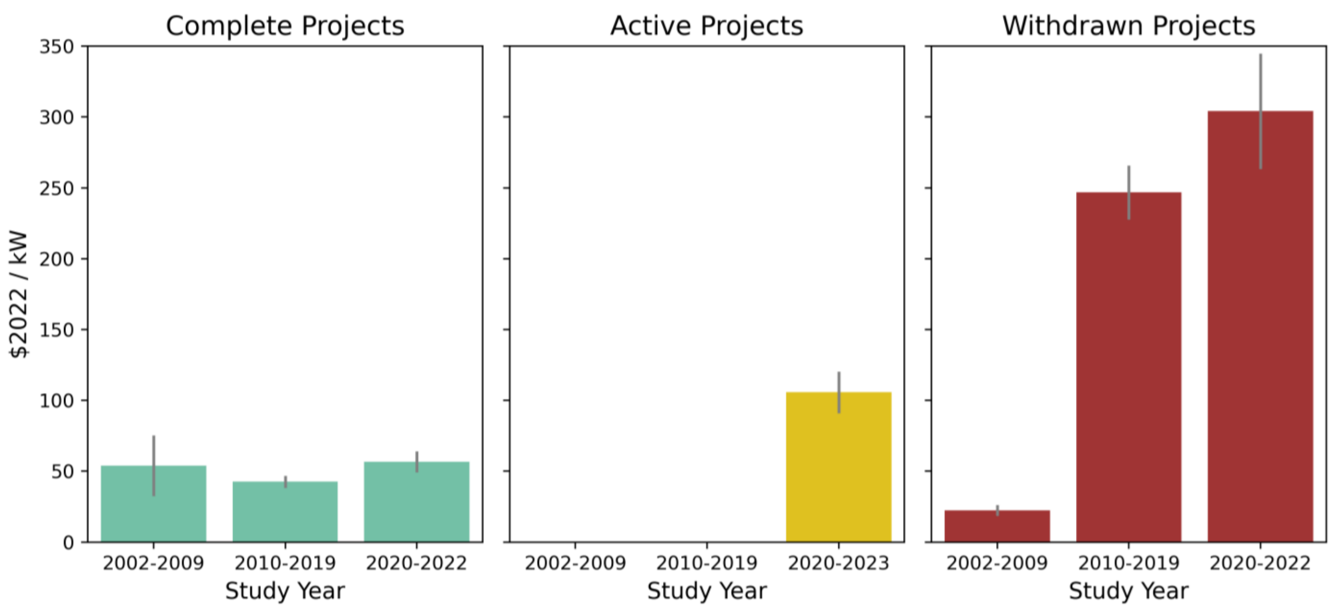

Figure 3. Interconnection Costs over Time by Request Status *(bars show simple means, gray lines represent standard error)*

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[2] Median costs increased for completed projects (from \$26 for both 2002-2009 and 2010-2019, to \$34/kW in 2020-2023). For withdrawn projects, costs increased eleven-fold from 2002-2009 (\$15/kW) to 2010-2019 (\$168/kW), and a bit further for 2020-2022 to \$184/kW.

[3] Median costs for withdrawn projects are more than five times the costs of complete projects over the period 2020-2022 (\$184/kW vs. \$34/kW) and nearly three times the cost of active projects (\$66/kW).

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3.2 Broader network upgrade costs are the primary driver of recent cost increases

We group costs identified in the interconnection studies into two large categories shown in Figure 4:

(1) Local interconnection costs describing investments at the point of interconnection (POI) with the broader transmission system. The FERC pro-forma Large Generator Interconnection Agreement refers to them as "Interconnection Facilities," while our study calls them POI costs. This study also includes "Stand Alone Network Upgrades" (or Non-Shared Network Upgrade Costs) that are identified in the Facility Studies in the POI cost category.[4]

(2) Broader network upgrade costs.[5]

Among projects that successfully complete all interconnection studies, local upgrades at the POI have historically dominated in SPP; in fact, in the early years (2002-2009), no project in our cost sample reported any network upgrade costs, and POI costs accounted for the entire interconnection costs of \$53/kW ($\hat{\sigma}_{\bar{x}}$=\$21/kW). Since then, POI costs have fallen to \$32/kW (2010-2019, $\hat{\sigma}_{\bar{x}}$=\$3/kW) before increasing again slightly to \$34/kW (2020-2022, $\hat{\sigma}_{\bar{x}}$=\$5/kW). Average network upgrade costs have grown to \$11/kW in 2010-2019 and \$23/kW in 2020-2022 ($\hat{\sigma}_{\bar{x}}$=\$3/kW and \$6/kW; Figure 4).[6] While average network upgrade costs now make up 40% of total interconnection costs for the most recent completed projects, only eight of these projects (9%) report network costs over \$100/kW. Finally, the magnitude of average network upgrade costs for recent complete projects is lower than what Berkeley Lab found for MISO (\$57/kW; Seel et al. 2022) and PJM (\$71/kW; Seel et al. 2023).

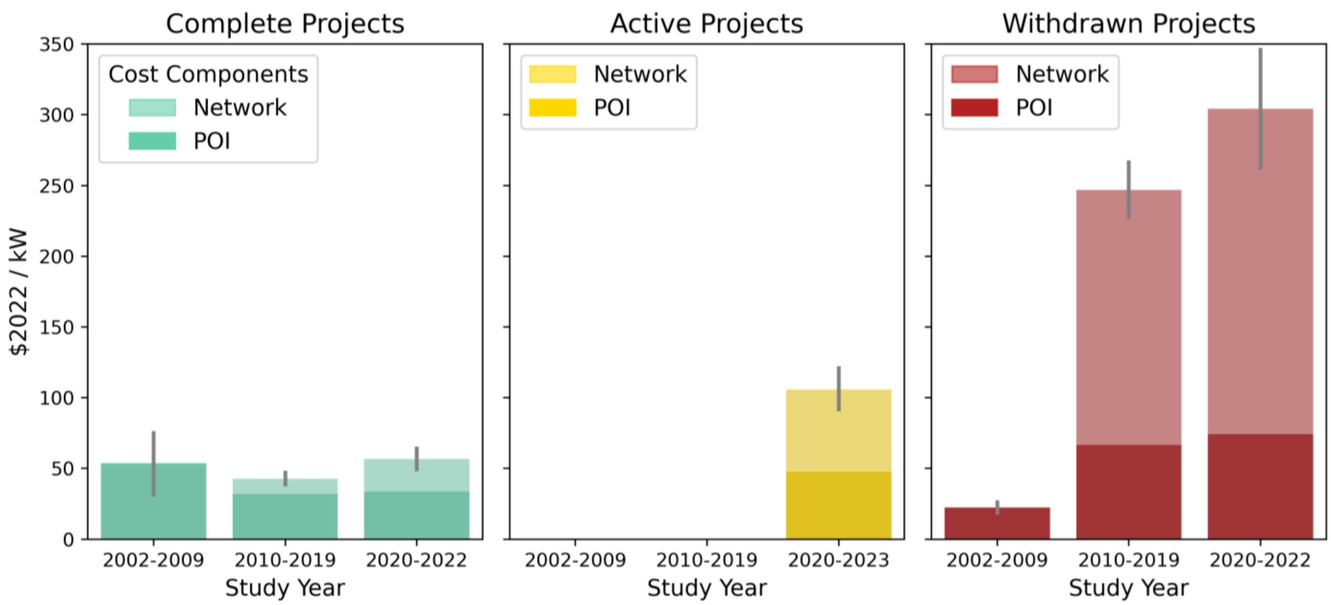

Figure 4. Interconnection Costs by Cost Category and Request Status *(bars: means, gray lines: standard error of total costs)*

[4] Reported POI costs in SPP interconnection studies are 1) *Transmission Owner Direct Assigned Interconnection Facilities* (referring to the construction of an interconnection station and transmission line extensions to those interconnection stations, also called TOIF) and 2) *Stand Alone Network Upgrades* (or *Non-Shared Network Upgrade Costs*) that are identified in the Facility Studies. They usually do not include electrical facilities at the generator itself, like transformers or spur lines (Interconnection Customer Interconnection Facilities).

[5] Network costs refer to the sum of *ERIS and NRIS network upgrades* (Feasibility and System Impact studies) shared network costs or costs associated with *Shared Network Upgrades* and *Affected System Upgrades* (Facility Studies). We exclude costs for *Contingent Network Upgrades*, *Previous Network Upgrades* or *Other Network Upgrades* from our reported network cost category.

[6] For complete projects, median POI costs also had a downward trend: \$24/kW (2002-2009), \$18/kW (2010-2019), and \$15/kW (2020-2022), and median network costs used to be \$0/kW (2002-2019) and are only \$2/kW now (2020-2022) (see also Figure 11 in the Appendix).

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The situation is different for projects that ultimately withdraw from the interconnection process. Although average POI costs at $22/kW were even lower than for complete projects in the early years (2002-2009, $\hat{\sigma}_{\bar{x}}$=$4/kW), they have since grown to $67/kW (2010-2019, $\hat{\sigma}_{\bar{x}}$=$11/kW) and finally to $74/kW in 2020-2022 ($\hat{\sigma}_{\bar{x}}$=$16/kW). But it is the required network upgrades that really set the withdrawn projects apart: they grew strongly to $180/kW (2010-2019, $\hat{\sigma}_{\bar{x}}$=$16/kW) and then on average even further to $230/kW (2020-2022, $\hat{\sigma}_{\bar{x}}$=$39/kW).[7] The top 10% of most recent network upgrade costs range between $859/kW and $1,238/kW, suggesting that outliers have a particularly large impact on our calculation of average costs.[8]

Among active projects, POI costs at $48/kW ($\hat{\sigma}_{\bar{x}}$=$4/kW) were higher in 2020-2023 than those for complete projects, but lower than those for withdrawn projects. Network costs at $58/kW ($\hat{\sigma}_{\bar{x}}$=$14/kW) were slightly greater than the POI costs, again falling in between the costs of complete and withdrawn projects.[9]

3.3 Interconnection costs for solar and wind are larger than for natural gas

Interconnection costs vary by the fuel type of the generator seeking interconnection, both in terms of the magnitude and composition of cost drivers. The cost sample contains primarily wind (487), solar (197), natural gas (70), and storage (68), but also some hybrid (9), coal (7), nuclear (2), and hydropower (1) plants.[10]

Solar ($157/kW) and wind ($154/kW) costs are greater than storage ($109/kW) and natural gas ($97/kW) costs when looking at all projects in our cost sample since 2010, irrespective of their request status (Figure 5, left panel).[11] Looking at complete projects, we find that natural gas interconnection costs increase from $18/kW (2002-2009, $\hat{\sigma}_{\bar{x}}$=$10/kW) to $27/kW (2010-2019, $\hat{\sigma}_{\bar{x}}$=$11/kW) and finally to $53/kW (2020-2022; only 1 project). Solar costs also climb on average from $54/kW (2010-2019, $\hat{\sigma}_{\bar{x}}$=$8/kW) to $99/kW (2020-2022, $\hat{\sigma}_{\bar{x}}$=$24/kW), though this is driven by a few projects with high interconnection costs. In contrast, wind costs have fallen from $65/kW (2002-2009, $\hat{\sigma}_{\bar{x}}$=$31/kW) to $46/kW (2010-2019, $\hat{\sigma}_{\bar{x}}$=$5/kW) to $43/kW (2020-2022, $\hat{\sigma}_{\bar{x}}$=$5/kW), potentially in response to recent transmission system expansions (Figure 5, center-left panel).[12]

For withdrawn projects, sampled costs increase over time for all fuel types (Figure 5, right panel). Natural gas interconnection costs expand from $3/kW (2002-2009, $\hat{\sigma}_{\bar{x}}$=$1/kW) to $181/kW (2010-2019, $\hat{\sigma}_{\bar{x}}$=$35/kW; no observations for 2020-2022). Withdrawn solar costs increase from an already high $316/kW (2010-2019, $\hat{\sigma}_{\bar{x}}$=$53/kW) to $394/kW ($\hat{\sigma}_{\bar{x}}$=$68/kW). Wind costs are a bit lower, but also grow on average from $25/kW (2002-2009, $\hat{\sigma}_{\bar{x}}$=$4/kW) to $244/kW (2010-2019, $\hat{\sigma}_{\bar{x}}$=$23/kW) to $263/kW (2020-2022, $\hat{\sigma}_{\bar{x}}$=$56/kW), though this most recent increase is driven again by a few high-cost projects. We only

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[7] For withdrawn projects, median POI costs showed less of a growth trend: $15/kW (2002-2009), $31/kW (2010-2019), and only $22/kW (2020-2022). Median network costs are $104/kW (2010-2019), but only $61/kW (2020-2022), see Figure 12 in the Appendix).

[8] See, for example, a facility study proposing upgrade costs of $147 million for a 152 MW wind project: https://opsportal.spp.org/documents/studies/files/2016_Generation_Studies/GEN-2016-110-IFS-2016-002-16_IFS-Summary_R0-FINAL.pdf

[9] For active projects, recent median POI costs are $29/kW. Median network costs at $16/kW are lower than POI costs, indicating that the reported mean in the main text is influenced by a smaller number of high cost projects.

[10] Coal projects were primarily studied between 2005 and 2008 and had average interconnection costs of $36/kW, coming nearly exclusively from POI costs. Hybrids were studied in 2022 and 2023 with interconnection costs ranging from $17/kW to $125/kW, coming mostly from POI costs, whereas two nuclear interconnection requests were assessed with $0/kW (2010) and $7/kW (2013). The one hydropower project had an assessment of $55/kW in 2011.

[11] $\hat{\sigma}_{\bar{x}}$ = $15/kW, $14/kW, $16/kW, and $19/kW. The trend is similar but more moderate when looking at median interconnection costs for solar ($80/kW), wind ($67/kW), storage ($73/kW) and natural gas ($49/kW), see Figure 14 in the Appendix.

[12] Median complete natural gas interconnection costs are $8/kW (2002-2009 and 2010-2019) and rise to $53/kW (2020-2022), solar costs remain mostly stable (2010-2019: $61/kW and 2020-2022: $59/kW), and wind costs fall from $33/kW (2002-2009 and 2010-2019) to $27/kW (2020-2022).

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have withdrawn storage cost estimates for the most recent period (2020-2022), when interconnection costs are high at \$285/kW ($\hat{\sigma}_{\bar{x}}$=\$23/kW).[13]

Interconnection cost estimates for active projects are only available from very recent system impact studies (2020-2023; Figure 5, center-right panel). For solar, these most current costs are lower at \$88/kW ($\hat{\sigma}_{\bar{x}}$=\$8/kW) than our complete and withdrawn estimates. For wind, costs of active projects are influenced by high-cost projects and average \$155/kW ($\hat{\sigma}_{\bar{x}}$=\$52/kW) – more than for complete projects, but lower than for withdrawn projects. Similarly, costs of active storage projects are \$95/kW ($\hat{\sigma}_{\bar{x}}$=\$15/kW), lower than their recently withdrawn peers.[14]

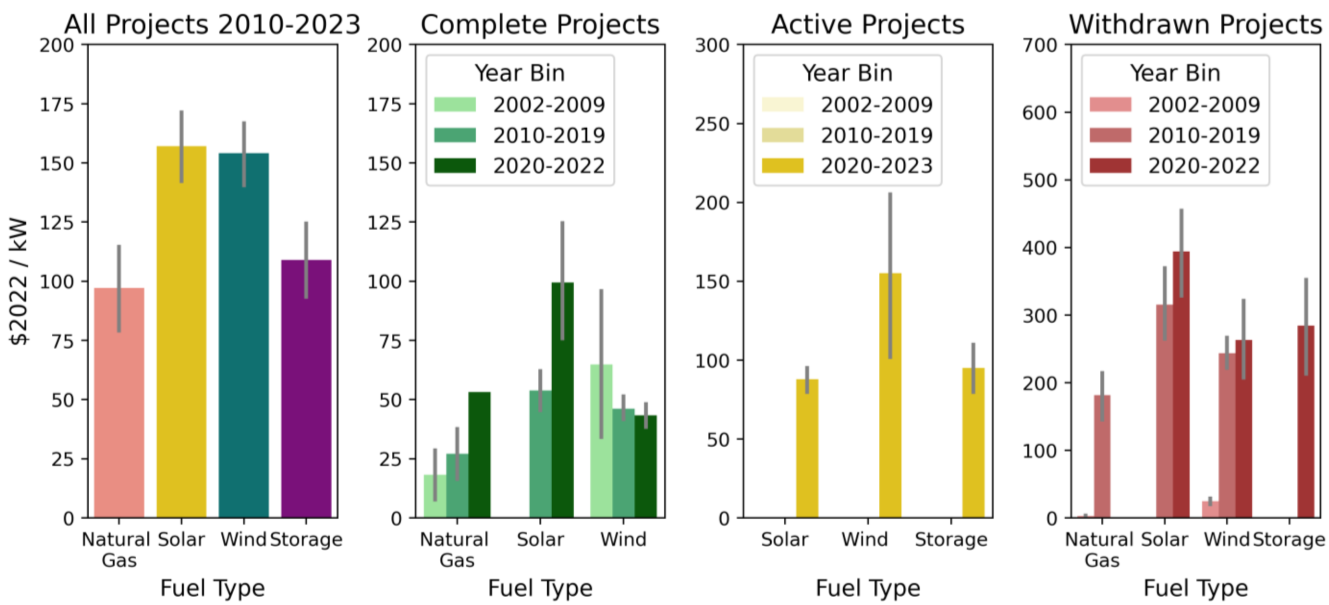

Figure 5. Interconnection Costs by Fuel Type *(left)* **and Over Time for Complete** *(center-left)*, **Active** *(center-right)* **and Withdrawn** *(right)* **Projects** *(bars: means, gray lines: standard error, y-axes differ by panel)*

For renewables that complete the study process, the most recent interconnection costs for wind are \$43/kW, or 3% of total 2021 wind project installation costs in SPP (Wiser et al. 2022); this compares to \$99/kW, or 6% of overall solar project installation costs in SPP in 2020 (Bolinger et al. 2022). Interconnection costs are thus similar to those in PJM (solar 7%, wind 4%) but lower than in MISO (solar 7%, wind 16%) (Seel et al. 2022; 2023). One potential driver of the larger interconnection costs for wind and solar may be siting differences, as renewable generators are typically located in more rural areas with fewer nearby substations. Recent high total interconnection costs among withdrawn solar projects of \$394/kW (25% of overall project installation costs; Bolinger et al. 2022) may explain why many solar projects abandon the queue. Total interconnection costs of withdrawing wind projects are lower at \$263/kW, but would still account for 17% of installed project costs (Wiser et al. 2022).

The breakdown of interconnection costs into POI and network costs also differs by fuel type. Figure 6 investigates the distribution of interconnection costs across all projects in our 2010-2022 sample. POI costs in our sample are somewhat higher for storage (active: \$57/kW, $\hat{\sigma}_{\bar{x}}$=\$12/kW, withdrawn: \$91/kW,

[13] Median withdrawn natural gas interconnection costs are the same as means at \$3/kW (2002-2009) rising to \$118/kW (2010-2019) (no estimates for 2020-2022). Median withdrawn solar costs increase from \$252/kW (2010-2019) to \$269/kW (2020-2022), and wind costs rise from \$17/kW (2002-2009) to \$168/kW (2010-2019) but then fall to \$85/kW (2020-2022). Withdrawn storage medians for 2020-2022 are \$218/kW.

[14] Median active costs for the 2020-2023 cohort are nearly constant: \$67/kW for solar, \$68/kW for wind, and \$72/kW for storage.

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$\hat{\sigma}_{\bar{x}}$=\$30/kW) and solar (complete: \$52/kW, $\hat{\sigma}_{\bar{x}}$=\$12/kW, active: \$43/kW, $\hat{\sigma}_{\bar{x}}$=\$5/kW, withdrawn: \$102/kW, $\hat{\sigma}_{\bar{x}}$=\$19/kW) than for wind (complete: \$31/kW, $\hat{\sigma}_{\bar{x}}$=\$3/kW, active: \$42/kW, $\hat{\sigma}_{\bar{x}}$=\$5/kW, withdrawn: \$63/kW, $\hat{\sigma}_{\bar{x}}$=\$12/kW) and natural gas projects (complete: \$23/kW, $\hat{\sigma}_{\bar{x}}$=\$8/kW, active: \$51/kW, $\hat{\sigma}_{\bar{x}}$=\$29/kW, withdrawn: \$35/kW, $\hat{\sigma}_{\bar{x}}$=\$8/kW). POI costs are also consistently higher for withdrawn projects than for complete projects – similar to what we found in MISO, but different from PJM.

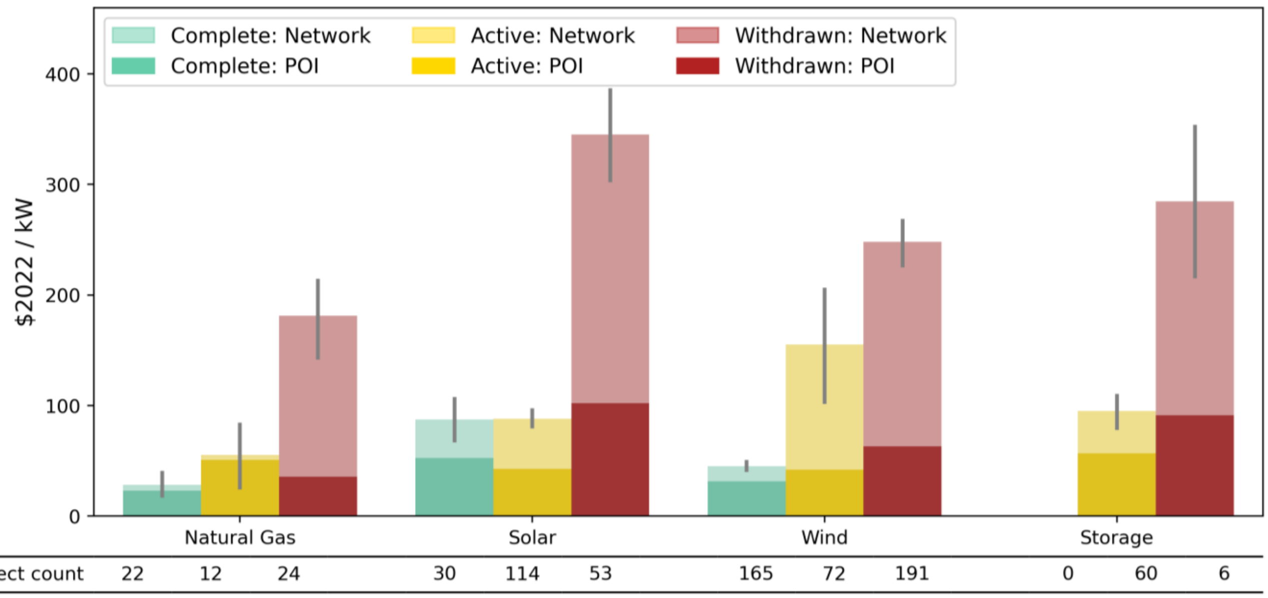

Figure 6. Interconnection Costs by Fuel Type, Cost Category, Request Status *(bars: means, gray lines: standard error of total costs, 2010-2023)*

However, the biggest cost driver for <u>withdrawn</u> projects within our sample are network expenses, which are modest for most complete projects. Withdrawn solar projects had seven times greater network costs than complete projects (\$243/kW vs. \$35/kW, $\hat{\sigma}_{\bar{x}}$=\$42/kW and \$16/kW); withdrawn wind projects had network costs 13 times higher than complete projects (\$185/kW vs. \$14/kW, $\hat{\sigma}_{\bar{x}}$=\$18/kW and \$3/kW); and withdrawn natural gas projects even saw 24-fold increase (\$146/kW vs. \$6/kW, $\hat{\sigma}_{\bar{x}}$=\$36/kW and \$4/kW).[15] We do not have network cost estimates for complete storage interconnection requests, but network costs clearly dominate among those that withdraw their applications (\$193/kW, $\hat{\sigma}_{\bar{x}}$=\$81/kW).

3.4 Only limited economies of scale exist, as larger projects can face greater network upgrade costs

Sampled projects with larger nameplate capacity ratings have greater average interconnection costs in absolute terms. Between 2010 and 2022, all potential projects smaller than 20 MW have average costs of \$2.9 million, which compares to \$8 million for medium-sized projects (20-100 MW), \$23 million for large projects (100-250 MW), and \$46 million for very large projects (250-1600 MW).

We find moderate evidence for economies of scale for interconnection costs. Across all applicants between 2010 and 2023, very small projects tend to have the lowest costs (\$221/kW), while medium and large projects average \$143/kW and \$151/kW, respectively. Very large projects (250-1600 MW) have lower average costs at \$119/kW.

[15] The findings for complete projects – that POI costs are consistently larger than network costs, whereas for withdrawn projects network costs dominate – also hold when looking at medians; see Appendix, Figure 13.

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Size efficiencies are primarily evident among POI costs, which decrease with increasing scale across all request statuses. Because network costs are reasonably stable for complete projects, we do find decreasing total relative costs here (1-20 MW: $15/kW, 20-100 MW: $60/kW, 100-250 MW: $53/kW, 250-675 MW: $43/kW; Figure 7). POI costs also decrease with size for projects that still move actively through the queue, accompanied by decreasing network upgrade costs for very large projects.[16] For withdrawn projects, network costs tend to increase with project size, leading to overall higher relative costs for larger projects. The greater investment need for large projects seems to enable some developers to select better sites, leading to lower interconnection costs relative to project size in SPP.

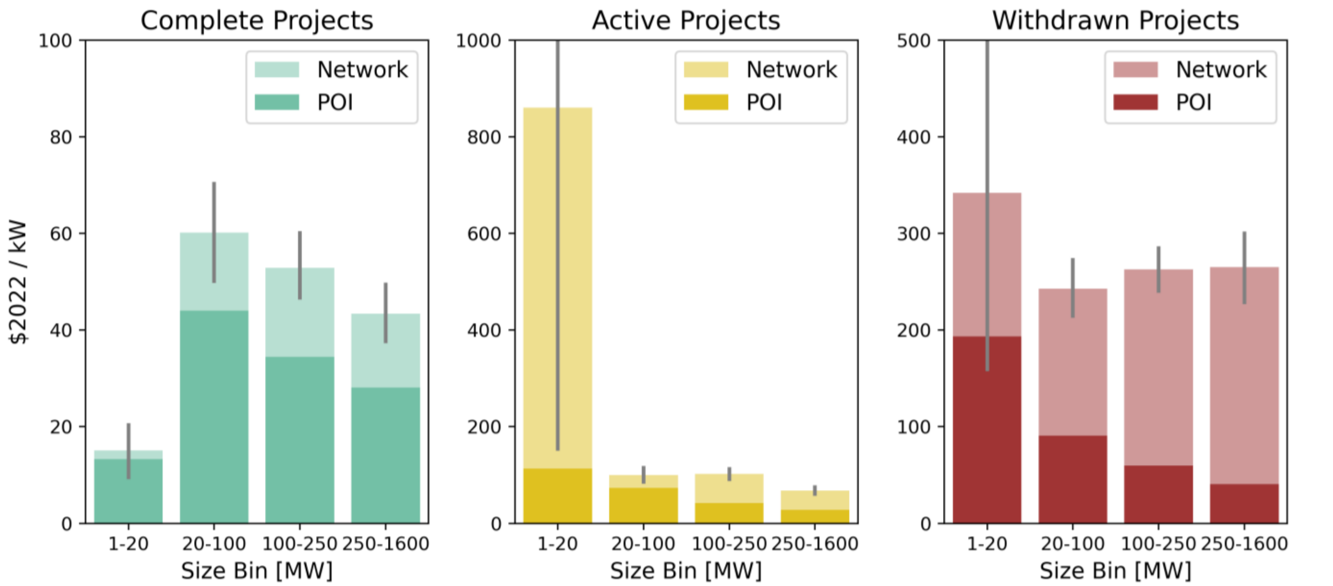

Figure 7. Interconnection Costs by Capacity and Request Status *(bars: means, gray lines: standard error of total costs, 2010-2023, y-axes differ by panel)*

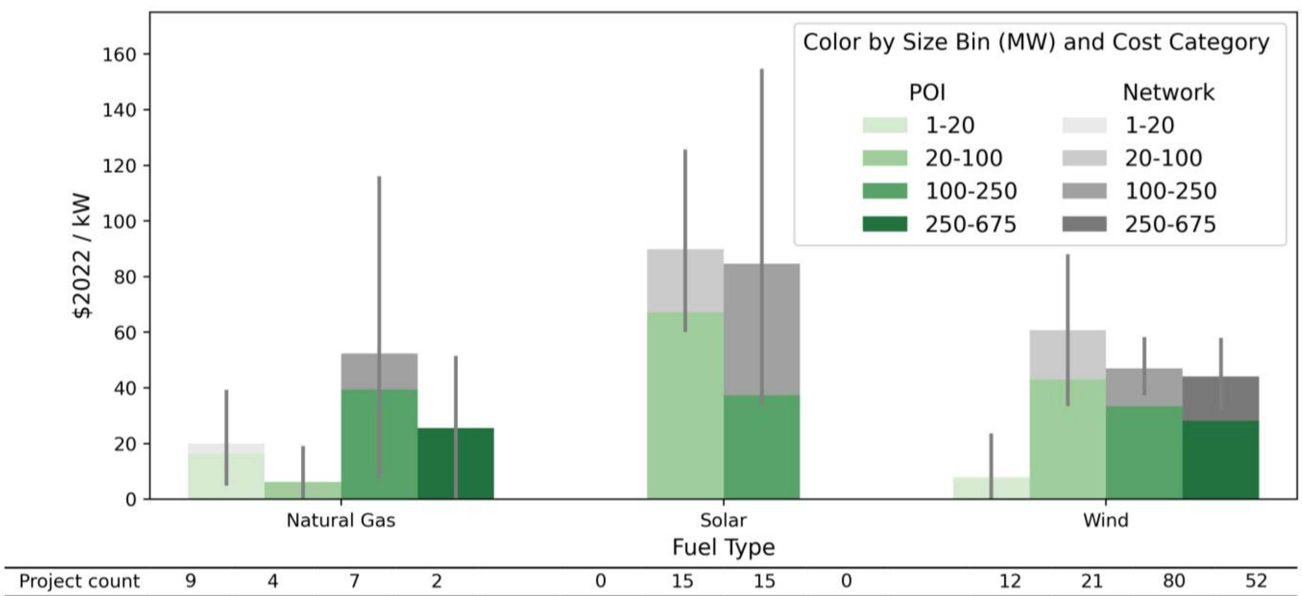

Figure 8. Interconnection Costs by Capacity and Fuel Type for Complete Projects *(darker color: POI costs, lighter color: network costs, bars: means, gray lines: standard error of total costs, 2010-2022)*

[16] The very high network cost of the 1-20 MW bin among active projects is influenced by one 18 MW wind project with assessed network costs of $3645/kW, as this subsample is very small with just five observations.

Economies of scale do not hold consistently in our cost sample when accounting for fuel type, especially among natural gas and storage projects (Appendix, Figure 15). Focusing only on complete projects, however, we find some evidence of declining costs with increasing project size for medium to large wind projects, and to a lesser extent for solar projects, but not for natural gas (Figure 8).

3.5 Interconnection costs vary by location, but regional trends are not very strong

Interconnection costs in our sample vary by location (Figure 9). Northern projects in South Dakota ($440/kW), Indiana ($419/kW), and Montana ($358/kW) report overall higher costs across all projects studied between 2010 and 2023, irrespective of whether they ultimately complete the interconnection process. Southern applicants in Oklahoma, Arkansas, and Missouri, on the other hand, have lower average interconnection costs ($84-95/kW).

Some southern states have comparatively high interconnection costs among complete projects in our sample (Louisiana: $212/kW, New Mexico: $80/kW). Costs for active projects seem rather uniform, except for South Dakota ($757/kW), Indiana ($419/kW), and Montana ($376/kW). A less clear pattern emerges for withdrawn projects, with high costs reported both in the north (South Dakota: $510/kW) and south. A general outlier seems to be the low costs in Oklahoma.

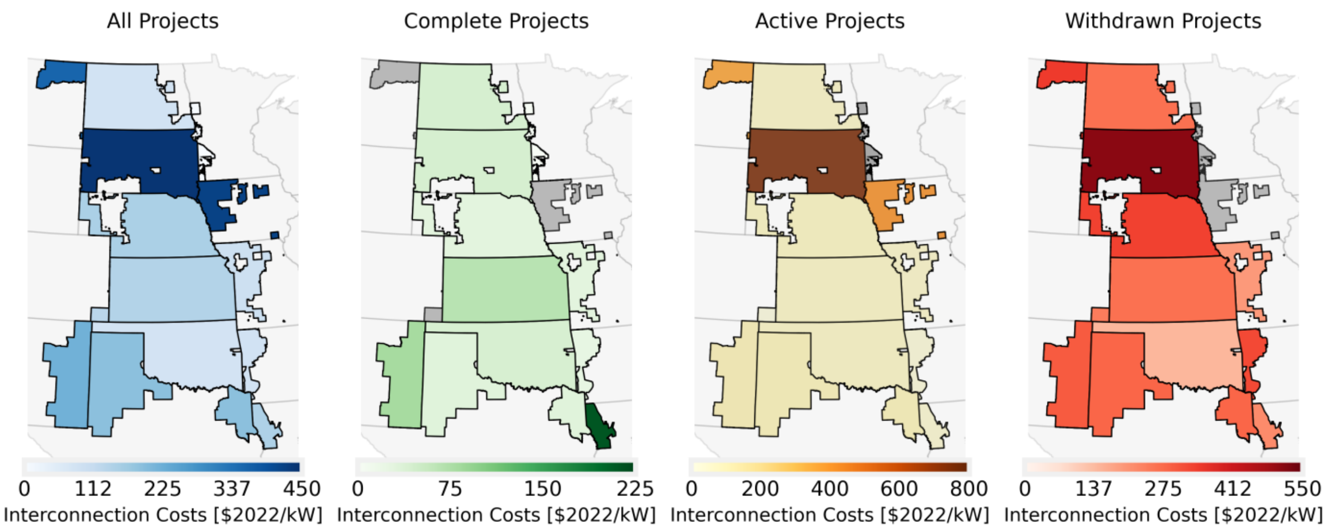

Figure 9. Interconnection Costs by State and Request Status, all Fuel Types *(means, 2010-2023, grey areas indicate no data)*

In the Appendix, Figure 19 to Figure 22 dive deeper into geographical cost distributions by fuel type. Natural gas projects report higher interconnection costs in Indiana and Texas than in North Dakota, Missouri, and Nebraska. For solar and wind, we do not find strong regional trends: South Dakota, for example, reports higher interconnection costs for active and withdrawn solar and wind projects but lower costs for complete projects. Storage interconnection studies find overall rather uniform costs across all active projects, though withdrawn storage assets faced particularly high costs in Texas.

Service Type

Generators seeking interconnection must choose between capacity (known in FERC's pro-forma LGIA as network resource interconnection service, NRIS) or energy service (known as energy resource interconnection service, ERIS). Capacity status reserves transmission capacity for the output of the generator during high load hours, for example allowing the project owner to have deliverable capacity that it can bid into resource adequacy markets. While capacity resources may still be curtailed during emergency events, they are treated preferentially in comparison to energy resources. This privilege comes with a cost however, as the generator may need to pay for additional transmission network upgrades. Energy service allows participation in the energy market and largely uses the existing transmission system on an as-available basis.

Looking at all interconnection requests in the SPP queue, including those for which we do not have cost estimates, we find that historically (request year 2000-2010) nearly no projects ultimately selected capacity services. However, starting with the 2017 cohort, most requests now favor capacity services; for entrants between 2020 and 2022 as many as 90% have selected capacity services, though some applicants may change their request to energy service after learning about the required upgrade costs during phase 1 of the system impact study. Our cost sample lags these trends a bit, as it takes time for interconnection cost analyses to be performed. Among all projects in our sample studied between 2010 and 2023, we still find that a small majority (56%) chose energy as the service type. While more recently popular solar and storage projects have mostly selected capacity service (64% and 59%), legacy natural gas (60%) and wind projects (64%) still favored the energy service option.

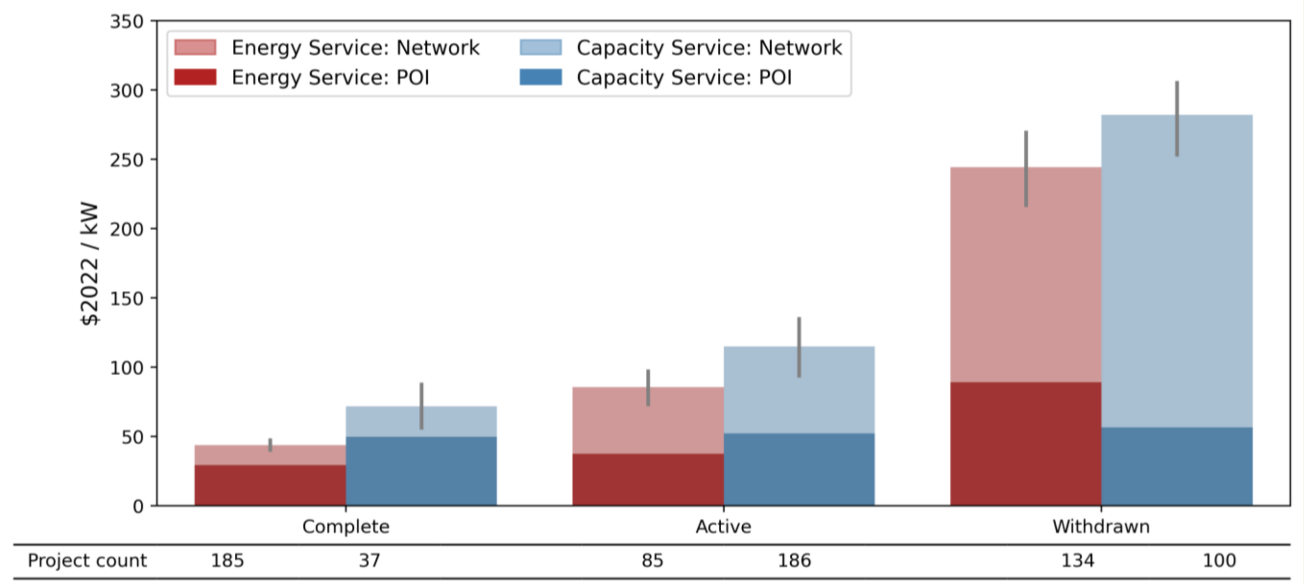

Figure 10. Costs by Service Type, Cost Category, Request Status *(bars: means, gray lines: standard error of total costs, 2010-2022)*

For our sampled projects studied between 2010 and 2023, the average interconnection costs for projects with capacity service are higher compared to those with energy service. Figure 10 inspects interconnection costs by request status and service type. Among projects that complete all interconnection studies, the average network cost difference is only minor (energy: $14/kW, capacity: $22/kW), but it grows for our active project sample (energy: $48/kW, capacity: $63/kW), and even more for those that ultimately withdraw (energy: $155/kW, capacity: $226/kW). It remains to be seen whether the trend of favoring capacity service that we observe in the broader queue and among our active projects will lead to rising interconnection costs among complete requests in the coming years. For now, the historical propensity for choosing energy service in SPP may explain why we observe lower interconnection costs compared to those in MISO, PJM, or NYISO.

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For other interconnection related work, see https://emp.lbl.gov/interconnection_costs and https://emp.lbl.gov/queues
For the DOE i2X program, see https://www.energy.gov/eere/i2x/interconnection-innovation-e-xchange
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4. Appendix

This Appendix is based on the same sampled data discussed in Section 2. It includes boxplot versions of the graphs in the core report, highlighting the broad distribution of interconnection costs that underlie the previously presented means. The boxplot median is highlighted with a bolder dashed line, and the lower and upper box line represent the 25th and 75th percentile, respectively. The lower/upper whiskers are 1.5x of the interquartile range below/above the 25th and 75th percentile. Not all outliers beyond the upper whiskers are shown in the graphs to preserve legibility but are included in the project-level cost data posted on our website (https://emp.lbl.gov/interconnection_costs). **Caution when comparing data between panels, as y-axes often differ** (to enable comparison of data within each panel).

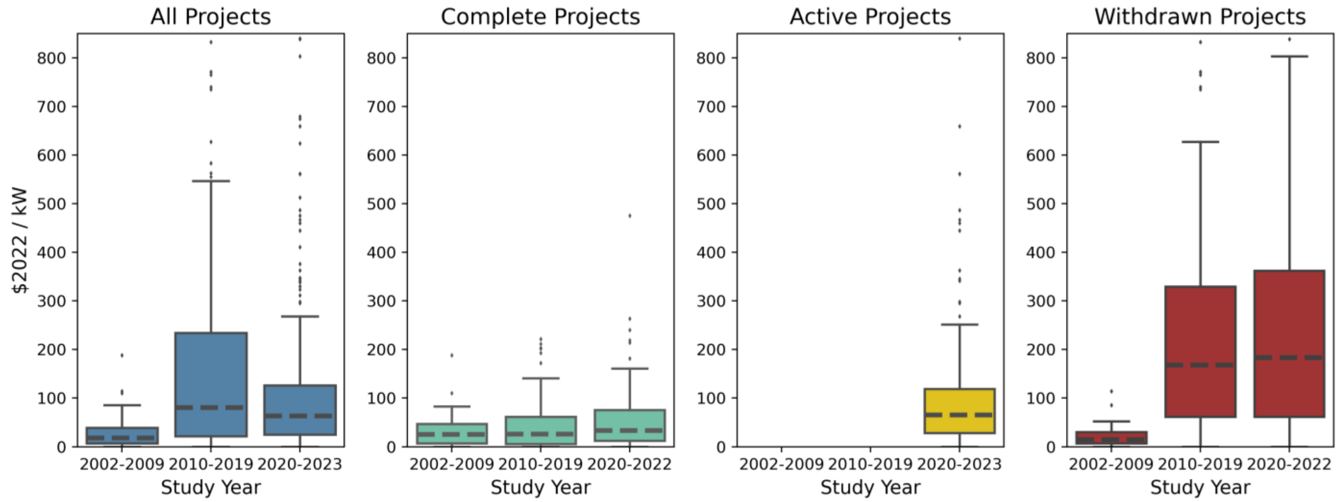

Figure 11. Interconnection Costs over Time by Request Status *(not all outliers outside 1.5x interquartile range are shown)*

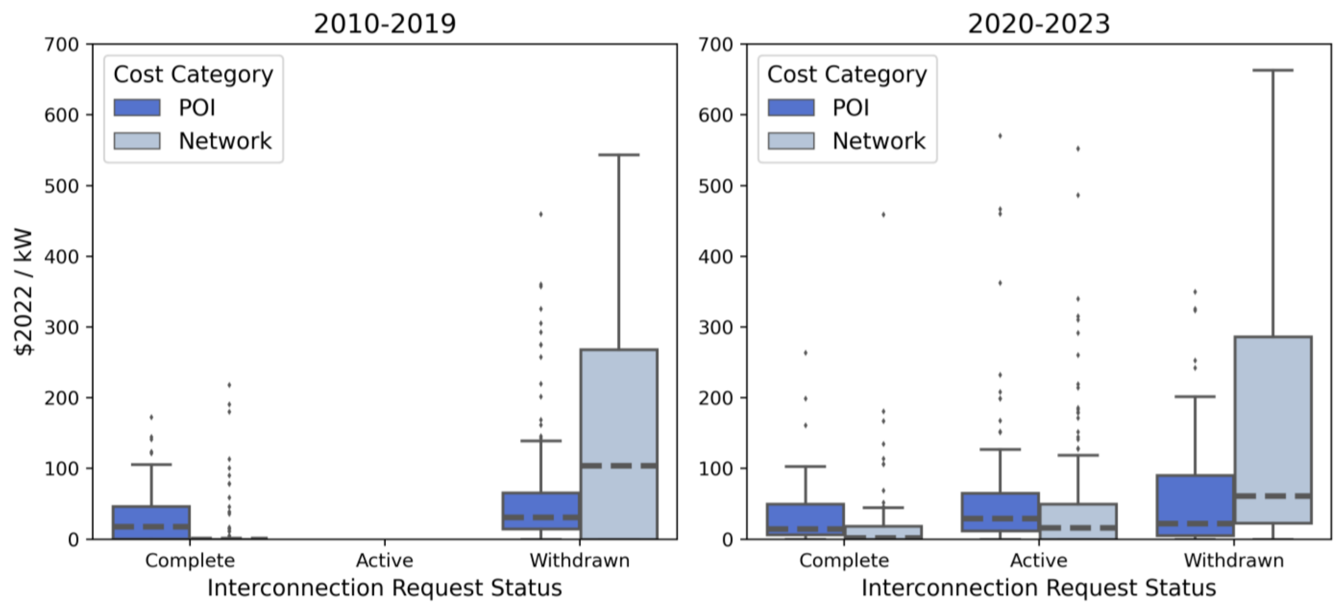

Figure 12. Interconnection Costs by Request Status and Cost Category *(not all outliers outside 1.5x interquartile range are shown)*

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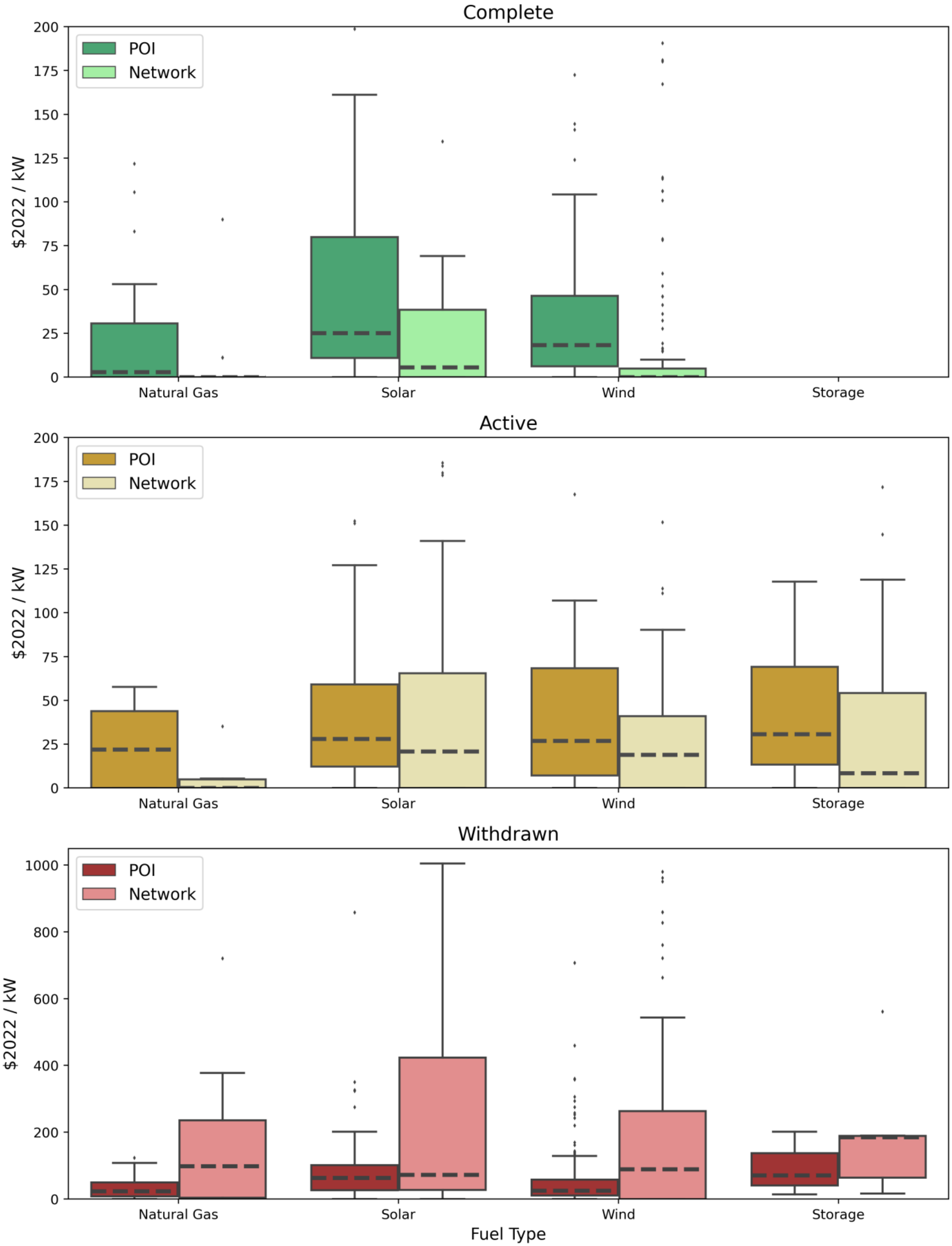

Figure 13. Interconnection Costs by Fuel Type, Request Status, and Cost Category *(2010-2023, y-axes differ by panel, not all outliers are shown)*

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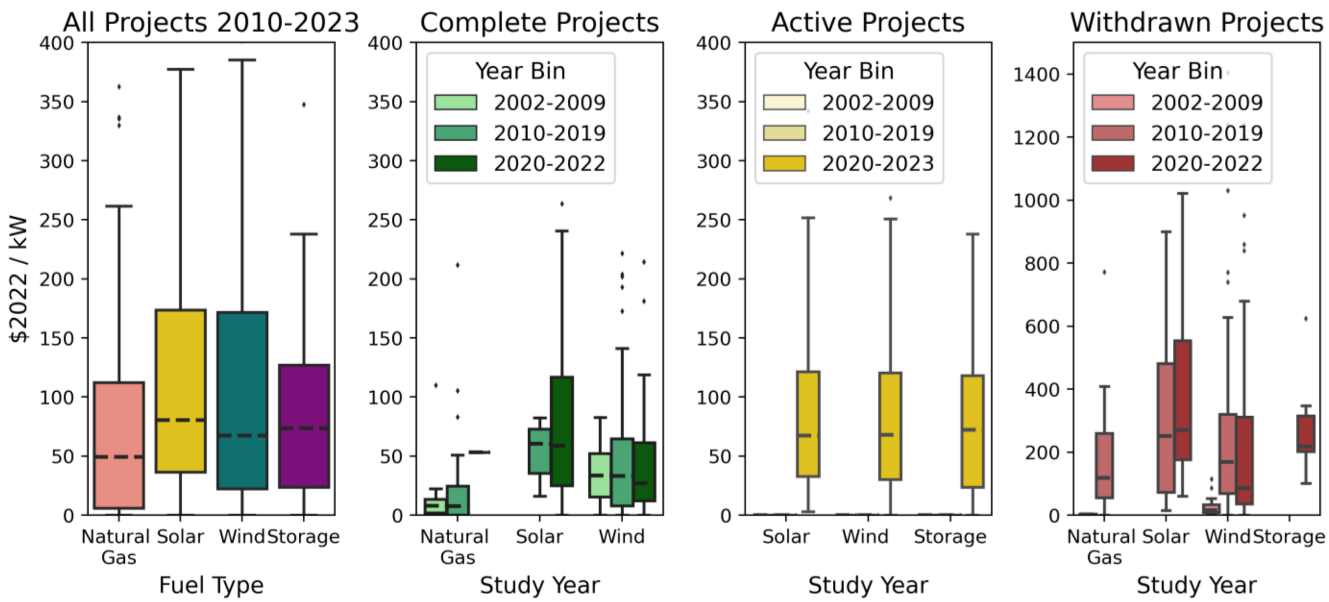
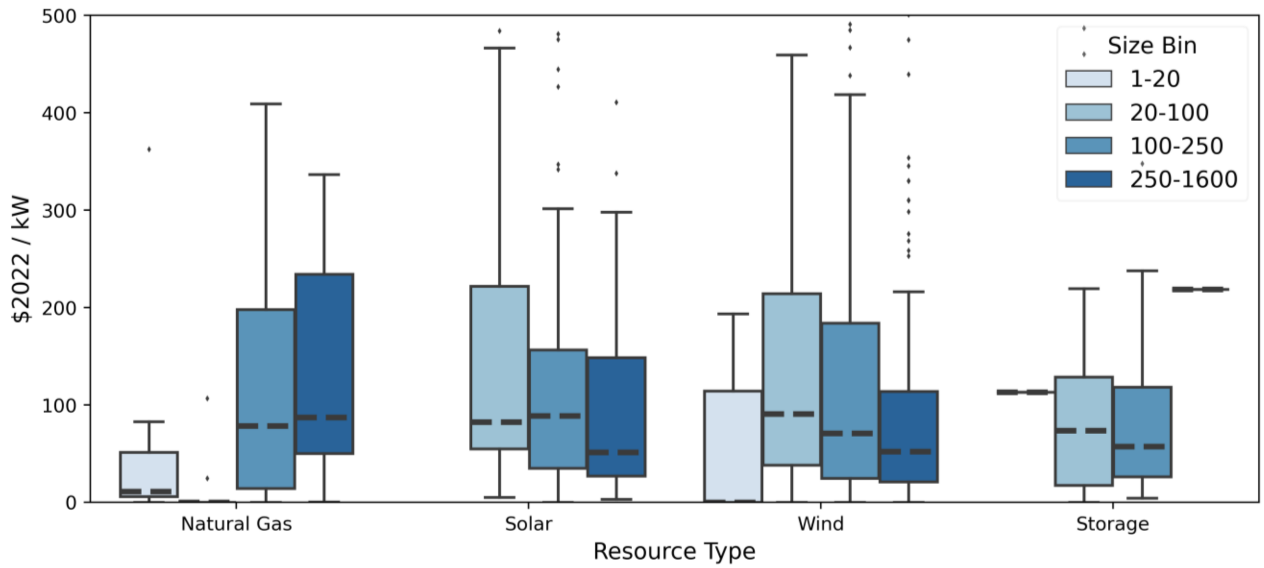


Figure 14. Interconnection Costs by Fuel Type *(left)* and Over Time for Complete *(center-left)*, Active *(center-right)*, and Withdrawn *(right)* Projects *(y-axes differ by panel, not all outliers are shown)*



Project count	14	10	14	20	0	57	94	46	22	69	222	114	1	38	28	1

Figure 15. Interconnection Costs by Fuel Type and Size Bin *(2010-2023, not all outliers are shown)*

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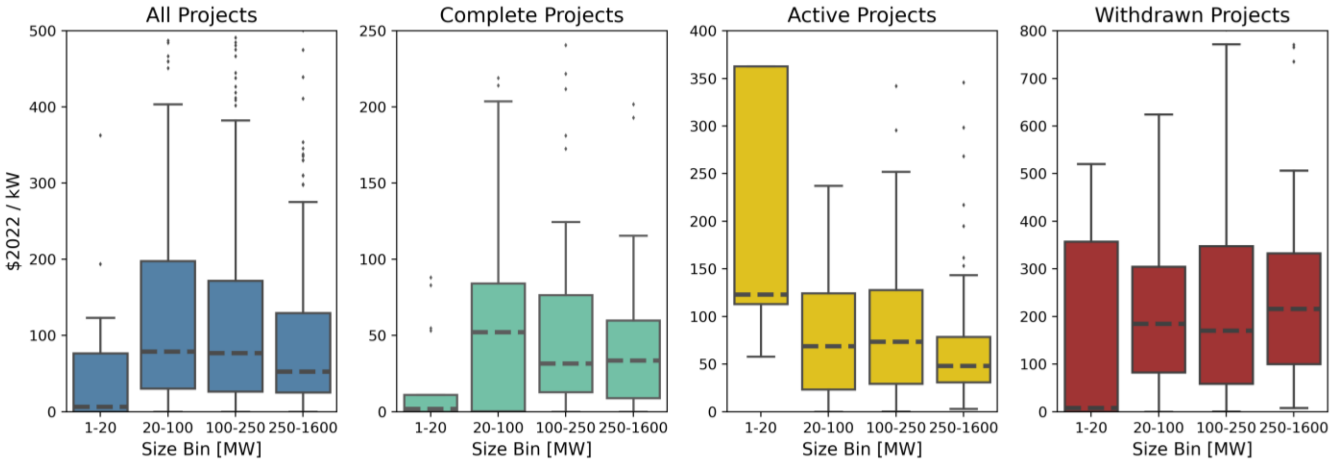

Figure 16. Total Interconnection Costs by Request Status and Size Bin *(2010-2023, y-axes differ by panel, not all outliers are shown)*

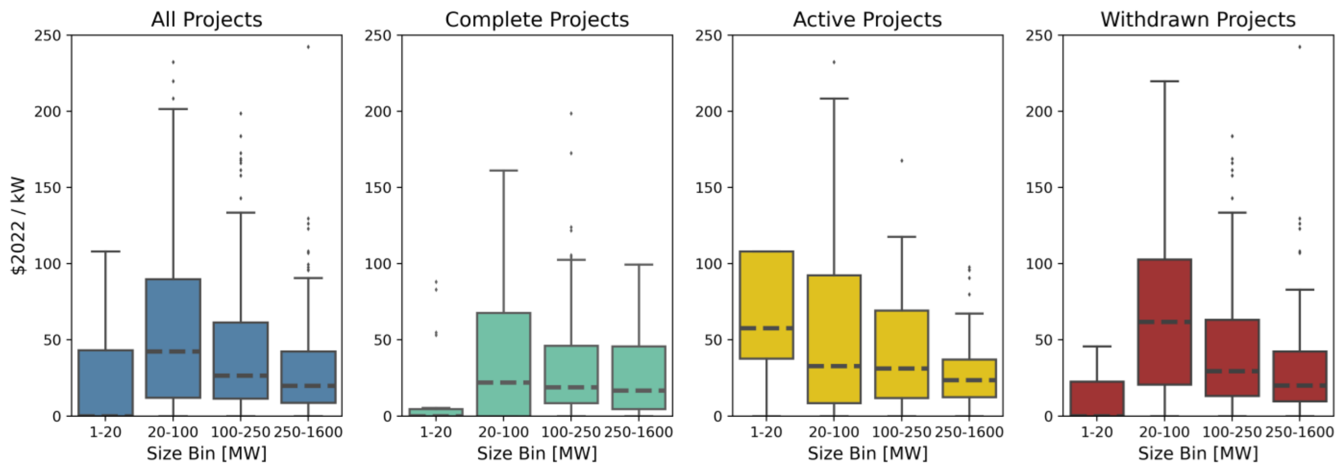

Figure 17. POI Interconnection Costs by Request Status and Size Bin *(2010-2023, not all outliers are shown)*

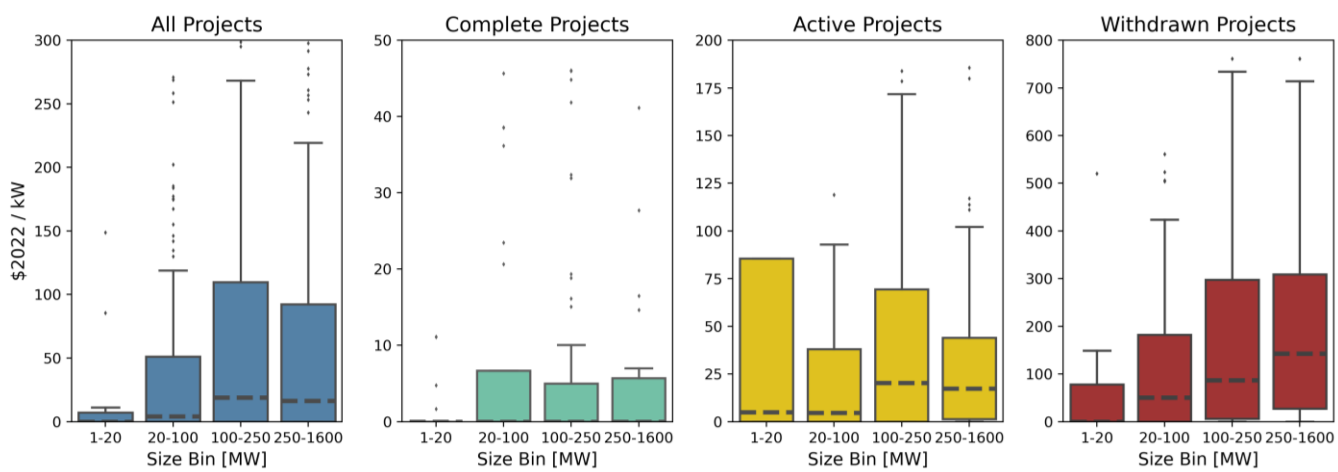

Figure 18. Network Interconnection Costs by Request Status and Size Bin *(2010-2023, y-axes differ by panel, not all outliers are shown)*

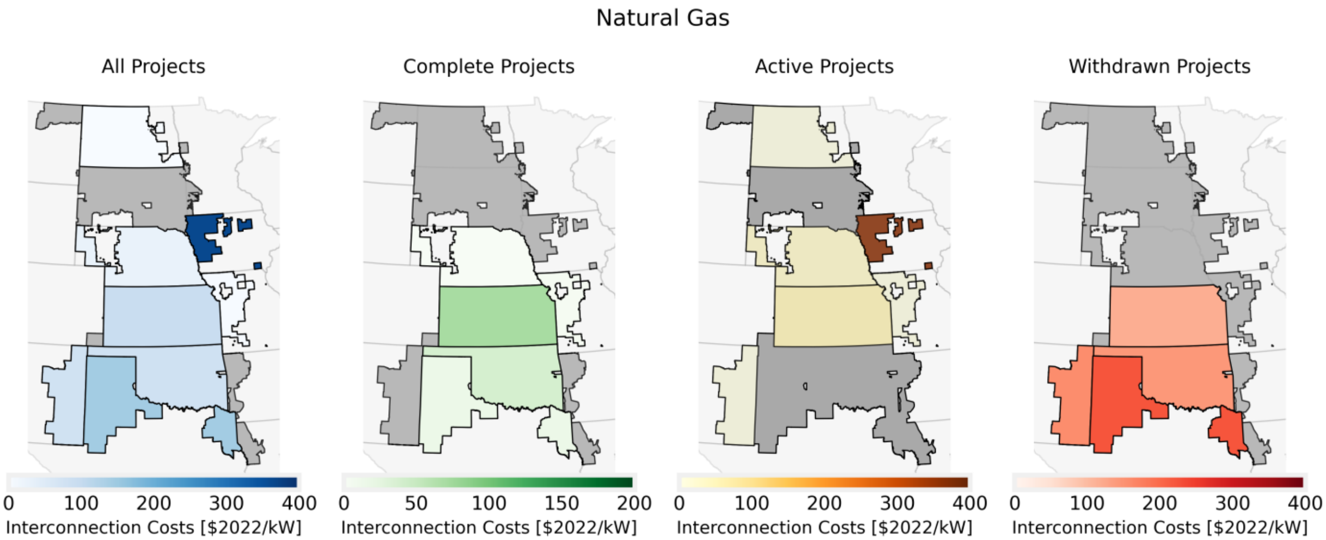

Figure 19. Interconnection Costs by State and Request Status: Natural Gas *(means, 2010-2023, grey areas indicate no data)*

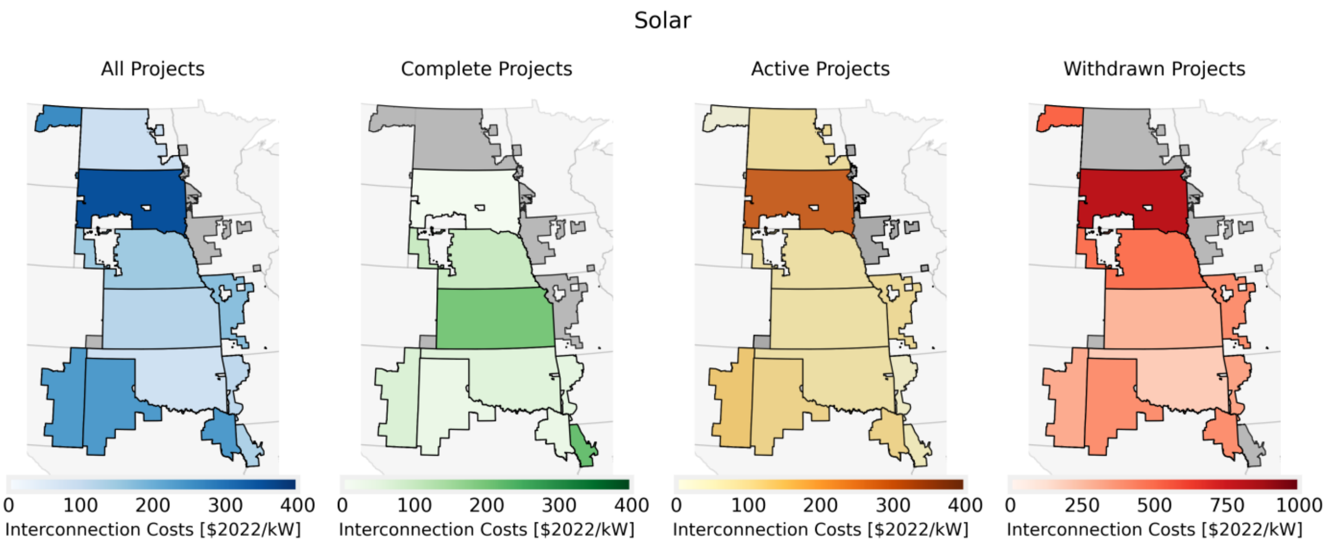

Figure 20. Interconnection Costs by State and Request Status: Solar *(means, 2010-2023, grey areas indicate no data)*

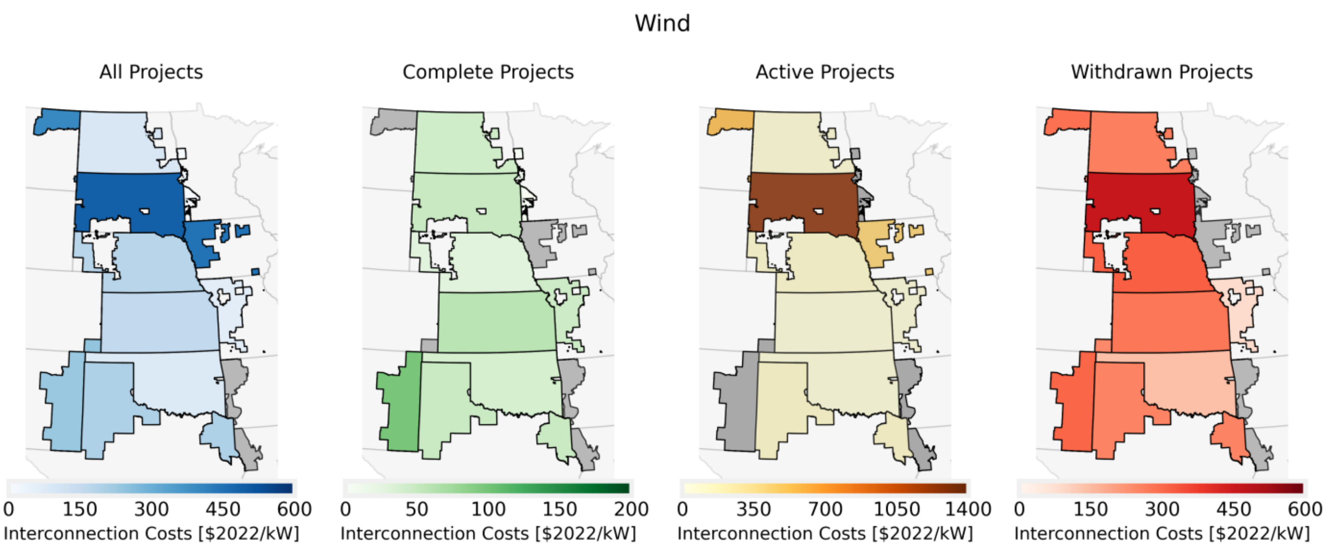

Figure 21. Interconnection Costs by State and Request Status: Wind *(means, 2010-2023, grey areas indicate no data)*

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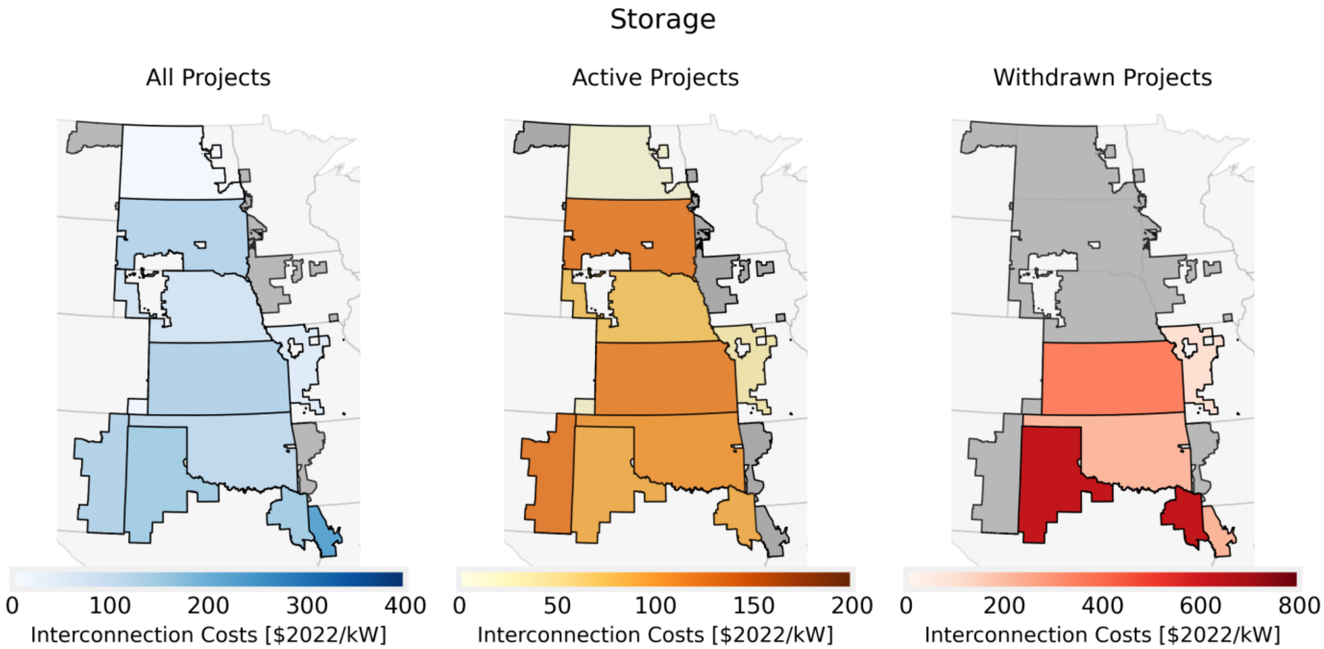

Figure 22. Interconnection Costs by State and Request Status: Storage *(means, 2010-2023, grey areas indicate no data)*

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