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Interconnection Cost Analysis in the Midcontinent Independent System Operator (MISO) Territory

Interconnection costs have escalated as interconnection requests have grown

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Executive summary

Interconnection queues have grown dramatically throughout the United States. In MISO, the cumulative capacity of projects actively seeking interconnection more than doubled from 2016 through 2021. Based on available data on project-level interconnection costs from MISO, our analysis finds:

- **Average interconnection costs have grown**. Project-specific costs can differ widely depending on many variables. We focus on average costs as a key cost metric. For projects that have completed all required interconnection studies (dubbed "complete" request status), average costs have nearly doubled (to $102/kW) for more recent projects relative to costs from 2000-2018 ($58/kW). Projects still actively moving through the queue ("active") have estimated costs that have more than tripled just over the last four years, from $48/kW to $156/kW (2018 vs. 2019-2021).
- **Projects that have completed all required interconnection studies have the lowest costs.** Costs averaged $102/kW for complete projects from 2019 through 2021. Projects that are actively progressing through the study process but have not yet completed all studies have higher costs ($156/kW), while the interconnection requests that ultimately withdraw from the queue ("withdrawn") face the highest costs ($452/kW)—likely a key driver for those withdrawals.
- **Broader network upgrade costs are the primary driver of recent cost increases.** Costs for local facilities at the point of interconnection are similar for complete ($46/kW) and active ($48/kW), but larger for withdrawn projects ($67/kW). Costs for broader network upgrades beyond the interconnecting substation explain most cost differences and have risen sharply. Estimated network upgrade costs have grown since 2018, to $57/kW for complete projects and $107/kW for active projects. Among withdrawn projects, they make up 85% of the costs at $388/kW for recent projects.
- **Potential interconnection costs of wind ($399/kW), storage ($248/kW), and solar ($209/kW) have been greater than natural gas ($108/kW) projects in recent years** (2018-2021). Wind projects bear the greatest costs compared to other resource types: Wind projects that completed the interconnection study process in 2021 faced a record average of $252/kW, nearly four times the historical average and about 16% of typical total wind installation costs in MISO. Wind projects that ultimately withdrew had average interconnection costs of $631/kW (equivalent to 40% of total project installed costs), compared with $358/kW (or 24% of installation costs) for withdrawn solar applicants.
- **Larger generators have greater interconnection costs in absolute terms, but economies of scale exist on a per kW basis.** Medium-sized wind ($491/kW) and solar ($259/kW) projects face twice the potential interconnection costs per unit of capacity compared to very large wind ($222/kW) and solar ($125/kW) projects.
- **Interconnection costs also vary by location**, with projects in the eastern part of MISO (Indiana and Illinois) reporting overall lower costs, irrespective of request status ($50-70/kW). Applicants in the north (North and South Dakota) and parts of Texas have high potential interconnection costs (average of $508-915/kW).

The cost sample analyzed here represents nearly 50% of all projects requesting interconnection from 2010 to 2020, or 30% when going further back in time to the year 2000. While it is sufficiently robust for detailed analysis, much data remains unavailable to the public. The paucity of easily accessible interconnection cost data poses an information barrier for 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.

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1. The interconnection queue doubled in capacity over the past few years

As of the end of 2021, the Midcontinent Independent System Operator (MISO) had over 160 gigawatts (GW) of generation and storage capacity actively seeking grid interconnection. This "active" capacity in MISO's queue is dominated by solar (112 GW) and, to a lesser extent, wind (22 GW) power capacity. MISO's queue also contains additional data for projects that are no longer actively seeking interconnection: 366 GW of projects have withdrawn their application and 62 GW of projects are already in service (Rand et al. 2022). Submissions for MISO's 2022 Generator Interconnection Queue again broke all records, increasing by 220% over 2021 levels. If all submissions are accepted as valid, the active MISO queue would balloon to 289 GW, more than 95% of which are either renewable power or energy storage (MISO 2022). The capacity associated with these requests is more than twice as large as MISO's peak load in recent years (about 120 GW) and, if substantial amounts are built, will likely exert competitive pressure on existing generation. However, most projects have historically withdrawn their applications: only 24% of all projects requesting interconnection between 2000 and 2016 have ultimately achieved commercial operation at the end of 2021.

MISO has implemented numerous interconnection process reforms since 2008 to reduce queue delays and project cancellations. These reforms, for example, shifted MISO's procedures for processing interconnection requests away from a "first-come, first-served" serial approach to a "first-ready, first-served" cluster study approach with annual cluster windows in each of the five MISO regions. In 2016, MISO introduced new "at risk" payments to enhance project readiness at interim milestones and, starting with the 2020 queue cycle, MISO established more stringent site control requirements for projects to progress through the queue (Bergan et al. 2012; Caspary et al. 2021). MISO has also increased efforts to expand the transmission network. The ISO recently approved $10 billion of new bulk transmission, while their Joint Targeted Interconnection Queue initiative aims to invest $1 billion to address transmission needs along the MISO-SPP seam.

2. Cost sample represents nearly 50% of projects requesting interconnection over the past decade

This brief analyzes interconnection cost data from 922 projects that were evaluated in interconnection studies between 2001 and 2021, equivalent to 28% of all projects requesting interconnection to the MISO system during that time (see left panel in Figure 1); the cost sample increases to 48% of projects when focusing on a more recent time period of 2011 through 2020.

Our interconnection cost sample has two sources:

- All data that were available in the MISO system as of February 2022: 698 projects (MISO 2022).
- Data for 224 additional projects that were already collected in 2018 and that had since been removed from the online MISO system (Gorman, Mills, and Wiser 2019).

While the sample is sufficiently robust to enable detailed analysis of interconnection costs, it represents a subset of all projects. MISO removes detailed interconnection study information after a few years from their publicly accessible records, explaining the paucity of data for earlier years. We were also not able to analyze costs for projects entering the queue in 2021 and beyond as interconnection studies with cost estimates are performed and published with some delay. The lack of easily accessible interconnection cost data poses an information barrier for 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 of the interconnection studies, and have moved on 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.

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

The sample varies over time with respect to request status (see right panel in Figure 1). Data for completed projects goes back furthest in time and makes up the largest portion of our cost sample (370 projects, 56.9 GW). Some projects ultimately withdraw from the interconnection process for a variety of reasons; our data includes 314 such projects (48.1 GW) that were studied between 2018 and 2021. Projects that are still active in the interconnection study process were primarily evaluated in 2021 (total of 238 projects, 37.8 GW).

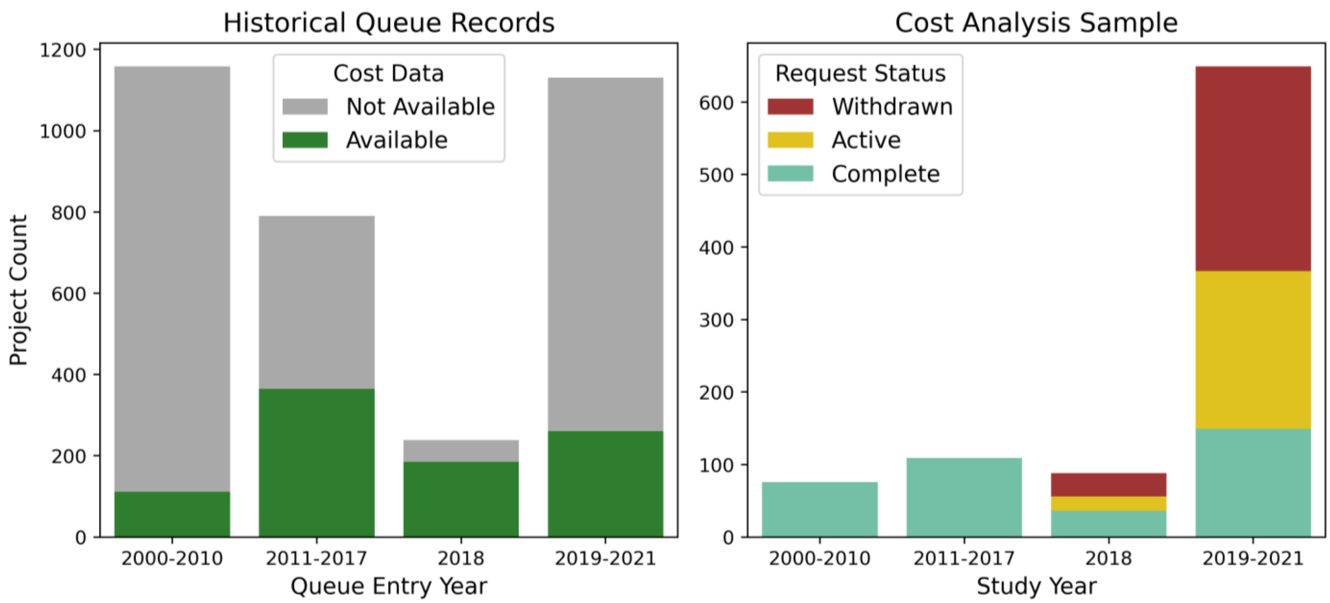

Figure 1 Sample: Availability of Cost Data Relative to Historical Queue Records *(left)*, **and Cost Data by Request Status** *(right). The left graph shows all historical projects seeking interconnection, indexed by their queue entry year. The right graph represents our cost analysis sample, with projects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

3. Interconnection costs have grown, driven by network upgrade expenses

Interconnection cost data were collected manually from public interconnection study reports, using the most recent study type available (feasibility studies, system impact studies, and addendums). The interconnection cost data summarized here are based exclusively on cost estimates in interconnection study reports and do not include potential additional interconnection-related expenses that may be borne by a project developer. We assume the reported costs refer to nominal dollars as of 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 textbox on the next page.

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 the core briefing as **simple means** to judge macro-level trends. Below is an illustrative example using completed project costs between 2018 and 2021. The histogram shows that more than 90% of all projects in this sample have interconnection costs under $200/kW, but a few cluster around $400/kW and one project has costs of $1,241/kW (Figure 2, left). Medians (dashed-line in the center of the boxplot) describe a "typical" project, with costs of $60/kW, but individual cost components cannot be added to meaningful sums. Means (Figure 2, right) are susceptible to the influence of a small number of projects with very high costs, and are often a bit higher than medians ($97/kW), but aggregated cost-components can easily be added. We include the standard error of the mean ($\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.

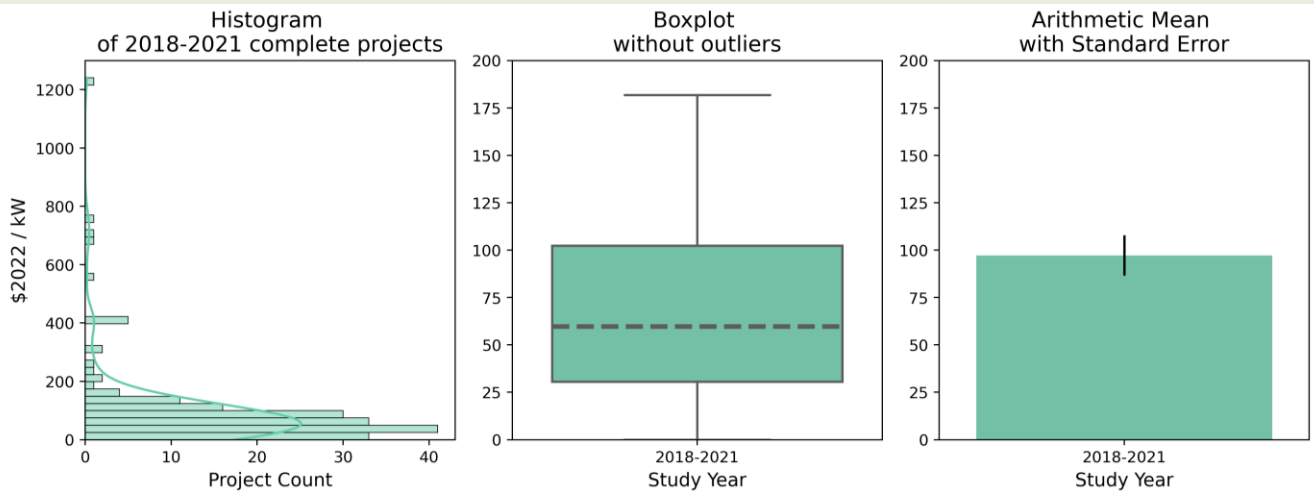

Figure 2 Interconnection Cost Metrics Example: Subsample of Projects that Complete Study Process, 2018-2021

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 are derived in the core briefing.

3.1 Average interconnection costs have grown over time

Potential interconnection costs across all applicants increase in our sample after 2000. However, combining all projects – regardless of request status – is problematic. Our cost sample composition changes over time, primarily containing completed projects in the early years, but with growing numbers of active and withdrawn projects in the later years (see Figure 1). Focusing on any given study cohort, one would expect that average interconnection costs would decline as projects proceed through the queue and high cost projects naturally withdraw.

But the trend of increasing interconnection costs also holds true when accounting for the request status of a project applicant (see Figure 3). Among the projects with completed interconnection studies, interconnection costs nearly double from $58/kW prior to 2019 to $102/kW between 2019 and 2021 (the standard error of the mean $\hat{\sigma}_{\bar{x}}$ $11/kW and $12/kW respectively). Projects that were still actively moving through the interconnection queues see more than a cost tripling, from $48/kW to $156/kW (2018 vs. 2019-

2021, $\hat{\sigma}_{\bar{x}}$=11&13). Projects that ultimately withdraw have stable costs at $453/kW and $452/kW (2018 vs. 2019-2021, $\hat{\sigma}_{\bar{x}}$=69&36).[1] Although average costs for withdrawn projects have remained stable, they are more than four times the costs of "complete" projects over the past four years ($453/kW vs. $147/kW, $\hat{\sigma}_{\bar{x}}$=33&12).[2]

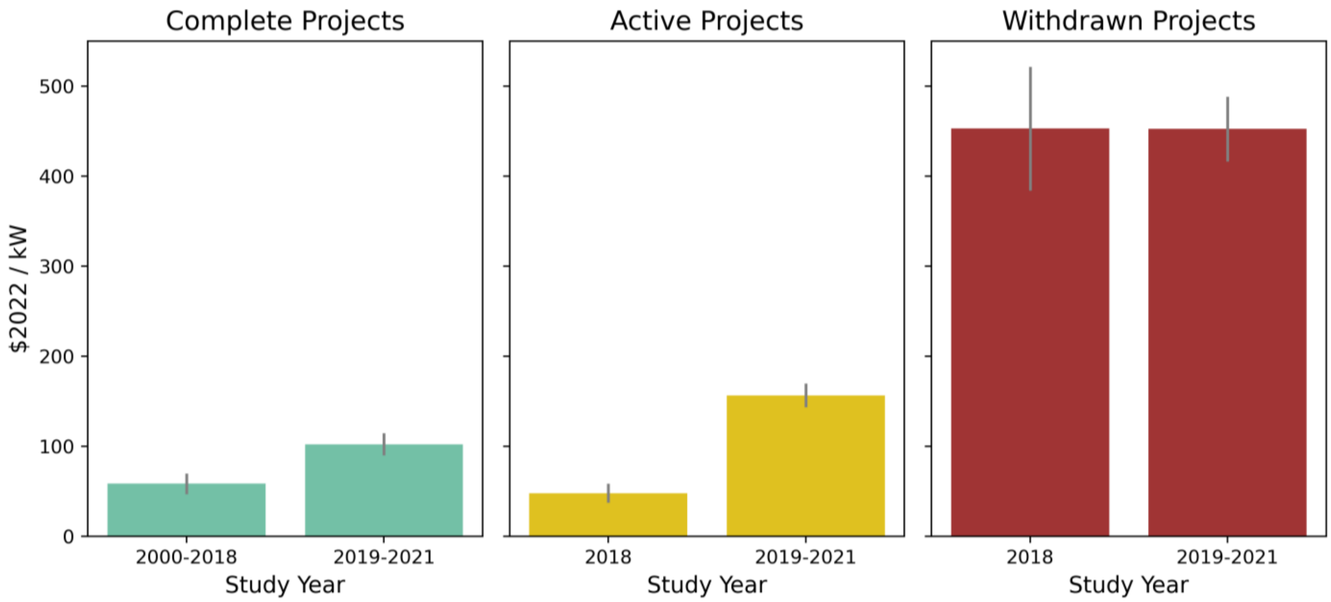

Figure 3 Interconnection Costs over Time by Request Status *(bars show simple means, gray lines represent standard error)*

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 facility costs describing investments at the point of interconnection (POI) with the broader transmission system, and (2) broader network upgrade costs.[3]

Among the projects that successfully complete all interconnection studies, local upgrades at the POI have historically been a significant cost driver, accounting for $46/kW (2018-2021, $\hat{\sigma}_{\bar{x}}$=3). A rise in these POI costs is also the primary reason for interconnection cost escalations since the early 2000s in this subsample. Yet, network upgrade costs can cause large cost additions for some projects and seem to be growing in recent years (from $31/kW in 2018 to $57/kW from 2019 to 2021, $\hat{\sigma}_{\bar{x}}$=17&12, Figure 4).[4]

Projects that are still being actively evaluated have similar POI costs, growing from $31/kW to $50/kW in the past four years ($\hat{\sigma}_{\bar{x}}$=7&4, Figure 4). However, network costs are the real cost driver: they are greater

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[1] Median costs grow fivefold for completed projects ($12 to $65/kW) and double for active projects ($46 to $95/kW). The trend among withdrawn is less clear when looking at medians: costs fall from $472/kW in 2018 to $171/kW in 2020 and rise again to $322/kW in 2021.
[2] Median costs for withdrawn projects are also four times the costs of complete projects over the period 2018-2021 ($265 vs. $60/kW).
[3] POI costs usually do not include electrical facilities at the generator itself like transformers or spur lines. Instead they are predominantly driven by the construction of an interconnection station and transmission line extensions to those interconnection stations. The categories are referred to as "Interconnection Facilities" in the interconnection studies and include Transmission Owner Network Upgrade and Transmission Owner-Owned Direct Assigned (or TOIF) expenses.
Network costs refer to upgrades classified as Backbone Network Upgrades, Thermal/Voltage/Steady State/Reactive/Transient Stability, Short Circuit, Local Planning Criteria, Affected System, Deliverability, and Shared Network Upgrade.
[4] For complete projects in 2018-2021, median POI costs are $35/kW, median network costs are $0/kW (see also Figure 10 in the Appendix).

compared to completed projects, again featuring at times projects with very high costs, and rising over the past four years from $16/kW to $107/kW ($\hat{\sigma}_{\bar{x}}$=10&13, Figure 4).[5]

The situation is very different for projects that ultimately withdraw from the interconnection process. While POI costs are typically a bit higher at $67/kW ($\hat{\sigma}_{\bar{x}}$=4, 2018-2021), the required network upgrades are commonly much larger and have grown in recent years from $366/kW to $388/kW ($\hat{\sigma}_{\bar{x}}$=65&36, Figure 4). The top 10% of network upgrade costs range between $900/kW and $4600/kW.[6] High network upgrade costs are often related to a lack of transmission in the geographic region of the applicant or high levels of congestion.

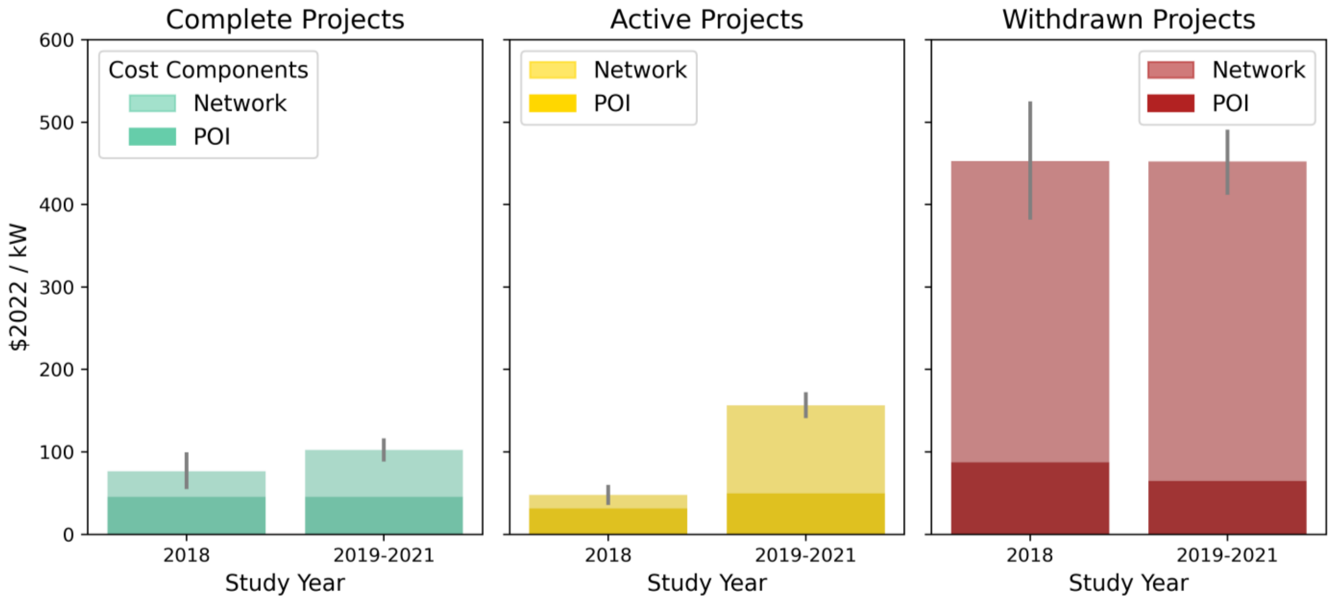

Figure 4 Interconnection Costs by Cost Category and Request Status *(bars: means, gray lines: standard error of total costs)*

Affected System Costs

Stakeholders have sometimes expressed particular concern about 'affected system' studies, which can result in assessed interconnection costs outside of the region to which the generator is interconnecting—an adjacent ISO, for example, and sometimes at great distance from the generator's proposed location. In part as a result, MISO and SPP have proposed reforming the affected system study process; so too has FERC, in its interconnection NOPR.

Between 2018 and 2021, regardless of request status, 27% of projects (196 in total) have listed estimates for 'affected system' interconnection costs. Among that subset, the average 'affected system' interconnection cost is $121/kW, representing usually half of the recorded network costs and on average 26% of their total interconnection costs; Costs are greater for wind ($186/kW) and solar ($62/kW) than natural gas ($18/kW). Projects that ultimately withdraw have higher affected system costs ($186/kW) than projects that complete all studies ($70/kW) or that are still actively seeking interconnection ($34/kW). Among projects that completed all interconnection studies, affected system costs have recently nearly quadrupled to $77/kW (2019-2021) compared with $21/kW in earlier years (2015-2018).

[5] For active projects in 2018-2021, median POI costs are $35/kW, median network costs are $30/kW (see also Figure 10 in the Appendix).
[6] For withdrawn projects in 2018-2021, median POI costs are $51/kW, median network costs are $160/kW (see Figure 10 in the Appendix).

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3.3 Interconnection costs for wind, storage, and solar 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 solar (409), wind (313), natural gas (79), and storage (57) projects, but in earlier years also some coal (20) and hydro (14) plants. Wind ($399/kW), storage ($248/kW), and solar ($209/kW) costs are greater than natural gas ($108/kW) costs when looking at all recent projects, irrespective of their request status (see left panel in Figure 5).[7]

The sample offers the longest time record for projects that complete interconnection studies. Looking at projects studied before and after 2019, we find that natural gas interconnection costs fall from $59/kW to $44/kW ($\hat{\sigma}_{\bar{x}}$=22&15). Cost escalations are evident, on the other hand, for renewables: average solar costs grow from $62/kW to $88/kW ($\hat{\sigma}_{\bar{x}}$=10), whereas wind costs double from $73/kW to $141/kW ($\hat{\sigma}_{\bar{x}}$=22&30, see right panel in Figure 5). Interconnection costs for wind escalated further when looking only at the year 2021, reaching $252/kW ($\hat{\sigma}_{\bar{x}}$=87) or nearly four times the historical average. Interconnection costs of this magnitude represent about 16% of total wind project installation costs in MISO (Wiser et al. 2022).[8] Interconnection costs of completed solar projects in 2021 are a smaller fraction of overall project costs, accounting for $99/kW ($\hat{\sigma}_{\bar{x}}$=23) or 7% of overall solar project installation costs in MISO in 2021 (Bolinger et al. 2022). 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.

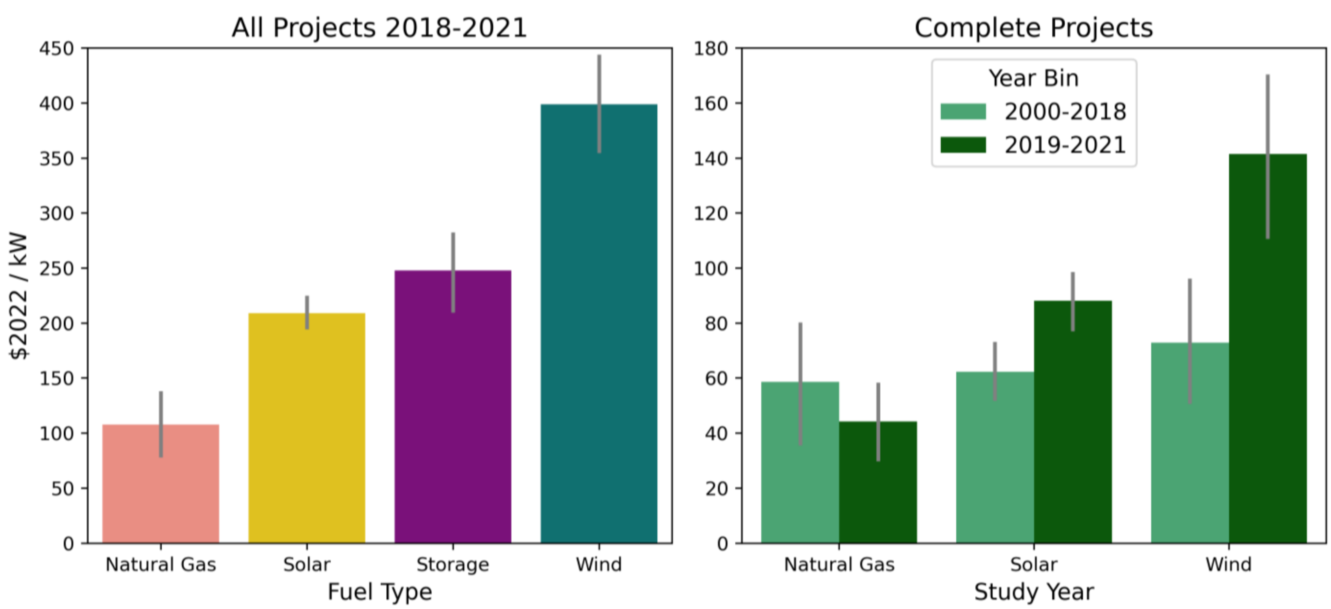

Figure 5 Interconnection Costs by Fuel Type (left) and Over Time for Complete Projects (right) *(bars: means, gray lines: standard error)*

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 2018-2021 sample. POI costs

[7] $\hat{\sigma}_{\bar{x}}$ = 44, 35, 14, and 29. The same trend is evident if we examine median interconnection costs for storage ($148/kW), wind ($107/kW), and solar ($104/kW) vs. natural gas ($31/kW), see Figure 12 in the Appendix. We only have one recent coal project, coming in at $29/kW.
[8] Median natural gas interconnection costs used to be negligible at $4/kW but rise to $43/kW, solar cost grow slightly from $59/kW to $65/kW, and wind costs double from $36/kW to $74/kW

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do not vary much, except for rather low costs for natural gas and unusually high POI costs for some storage projects. The high storage costs may be driven by storage dispatch assumptions used in the interconnection studies that presumed storage to charge during high load hours.

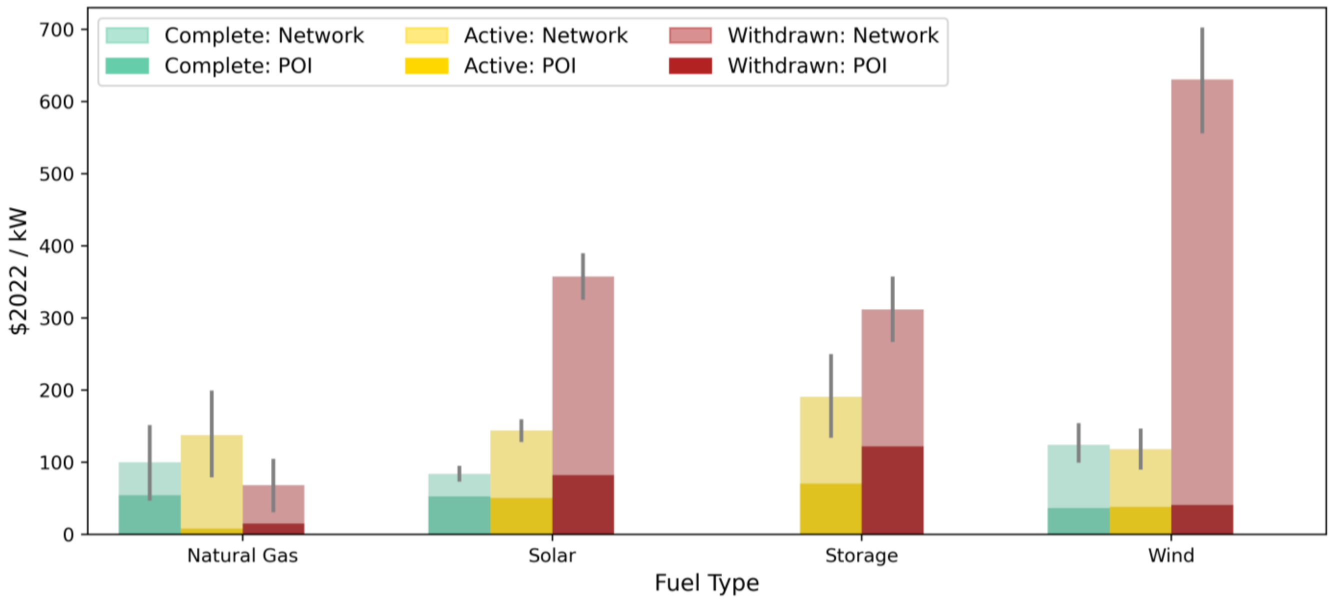

Figure 6 Interconnection Costs by Fuel Type, Cost Category, Request Status *(bars: means, gray lines: standard error of total costs, 2018-2021)*

In contrast, network costs increase dramatically for <u>active</u> and <u>withdrawn</u> projects. Network costs are three times greater than POI costs for withdrawn solar projects ($275/kW vs. $82/kW) and fifteen times greater for withdrawn wind projects ($590/kW vs $40/kW).[9] High total interconnection costs of $631/kW ($\hat{\sigma}_{\bar{x}}$=73, or 40% of overall wind project installation costs (Wiser et al. 2022)) could explain why wind projects withdraw from the queue. Total interconnection costs of withdrawing solar projects are lower at $358/kW ($\hat{\sigma}_{\bar{x}}$=30), but would still account for 24% of installed project costs (Bolinger et al. 2022).

3.4 Larger generators have greater interconnection costs in absolute terms, but economies of scale exist on a per kW basis

Projects with larger nameplate capacity ratings have greater interconnection costs in absolute terms, on average and irrespective of whether projects ultimately come online or withdraw. Between 2018 and 2021, projects smaller than 20 MW have average costs of $7 Million, which compares to $16 Million for medium-sized projects between 20 and 100 MW, $40 Million for large (100-250 MW), and $65 Million for very large (250-1500 MW) projects.

But these costs do not scale linearly on a per kW basis. Costs fall from $705/kW for small projects to $283/kW, $259/kW, and $167/kW for medium, large, and very large project sizes, respectively, suggesting substantial economies of scale.[10] The size efficiencies generally hold both for POI and network costs—very large projects thus do not seem to bear atypically high interconnection costs or trigger unusually costly

[9] $\hat{\sigma}_{\bar{x}}$ for withdrawn solar are 29 & 6, for wind 72 & 3. Median network costs are two times greater than POI costs for withdrawn solar projects (median: $123 vs $65/kW) and ten times greater for wind projects ($347 vs $35/kW).
[10] $\hat{\sigma}_{\bar{x}}$ across size bins are 311, 32, 18, and 26.

network upgrades. In fact, the larger initial investment may enable developers to preselect better sites that result in lower interconnection costs relative to project size.

Economies of scale also persist across the three different requests statuses (see Figure 7). Very small projects that complete the study process seem to have atypically low costs ($9/kW), but this subsample is small (6 observations) and therefore may be skewed – small active and especially small withdrawn projects have much higher costs, driven by very large network upgrade costs relative to their size.

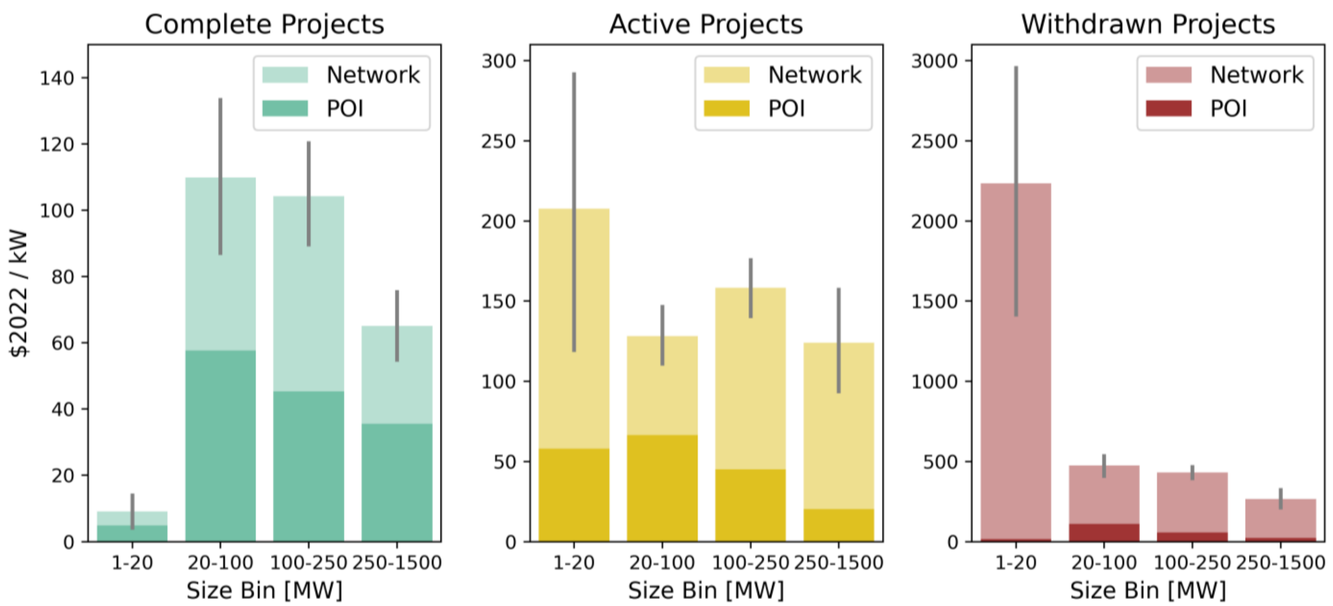

Figure 7 Interconnection Costs by Capacity and Request Status *(bars: means, gray lines: standard error of total costs, 2018-2021, y-axes differ by panel)*

Economies of scale largely hold when accounting for fuel type: Medium solar projects (20-100 MW) have greater costs ($259/kW) compared to large (100-250 MW: $200/kW) or very large projects (250-1500 MW: $125/kW), and the same is true for wind projects (20-100 MW: $491/kW, 100-250 MW: $373/kW, 250-1500 MW: $222/kW).[11] Costs for natural gas and storage, on the other hand, do not vary significantly by size (see Appendix, Figure 13).

We can only compare longer time trends for the subsample that has completed the interconnection studies, but find that larger projects have consistently lower costs compared with their smaller counterparts since 2010, and a per-kW basis.

3.5 Interconnection costs vary by location

Interconnection costs also vary by location, with eastern projects in Illinois ($50/kW) and Indiana ($69/kW) reporting overall lower costs across all projects studied between 2018 and 2021 (irrespective of whether they ultimately complete the interconnection process). Applicants in North and South Dakota and parts of Texas, on the other hand, have high average interconnection costs ($508-915/kW). Overall there is some alignment between states with high interconnection costs and those with little available transmission capacity, which are located primarily in in the north of the ISO (MISO, 2022).

[11] $\hat{\sigma}_{\bar{x}}$ for solar across size bins are 38, 14, 28; $\hat{\sigma}_{\bar{x}}$ for wind are 142, 45, 48.

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Figure 8 examines cost variation by state and project status request: Northern states have again comparatively high interconnection costs among complete (Minnesota: $159/kW) and withdrawn (North Dakota: $1001/kW) projects, while eastern projects in Illinois and Indiana are assigned lower costs ($42/kW and $43/kW for completed; $28/kW and $60/kW for withdrawn projects). Southern states such as parts of Texas ($416/kW) and Louisiana ($306/kW) have the greatest interconnection costs among projects that are still actively being assessed.

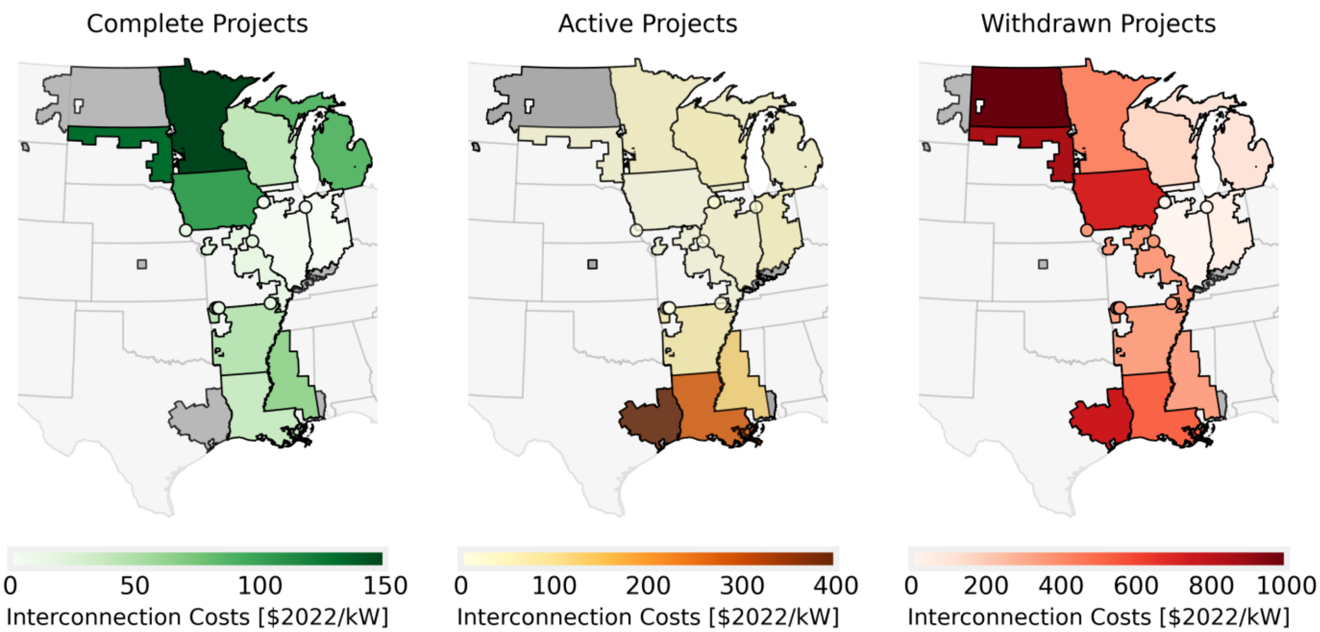

Figure 8 Interconnection Costs by State and Request Status *(means, 2018-2021, grey areas indicate insufficient data)*

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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 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, the lower and upper box line represent the 25th and 75th percentile. The lower/upper whiskers are 1.5x of the interquartile range below/above the 25th and 75th percentile. Not all outliers are shown to keep the graphs legible. Y-axes may differ by panel.

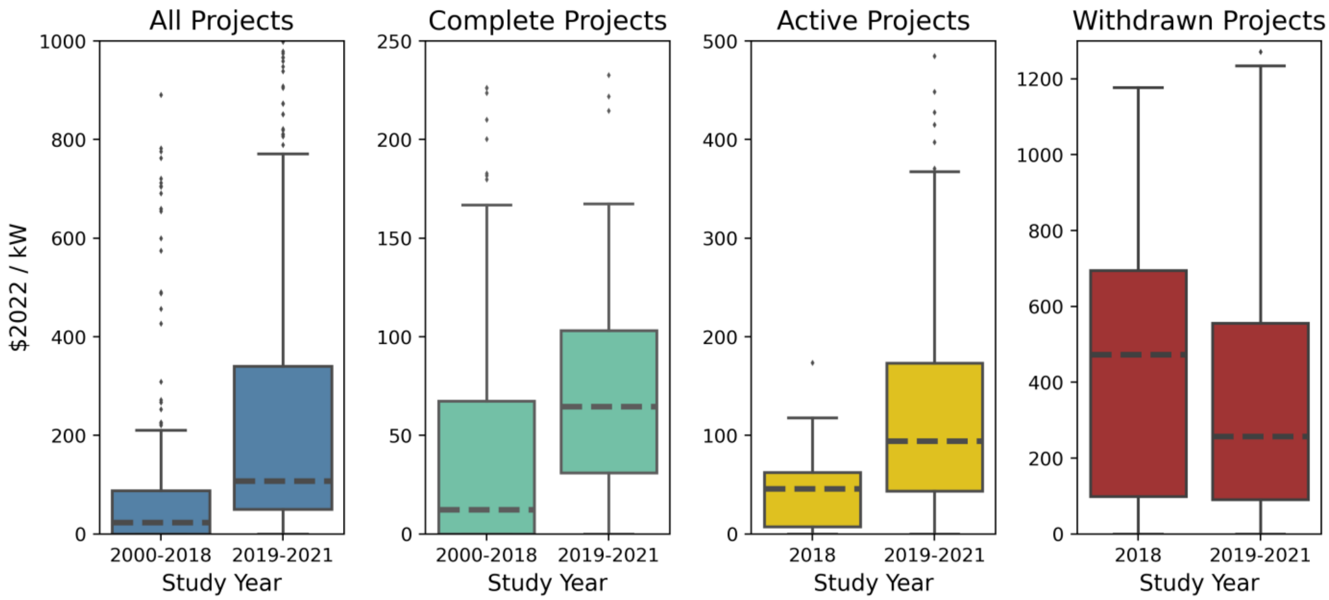

Figure 9 Interconnection Costs over Time by Request Status *(y-axes differ by panel, not all outliers outside 1.5x interquartile range are shown)*

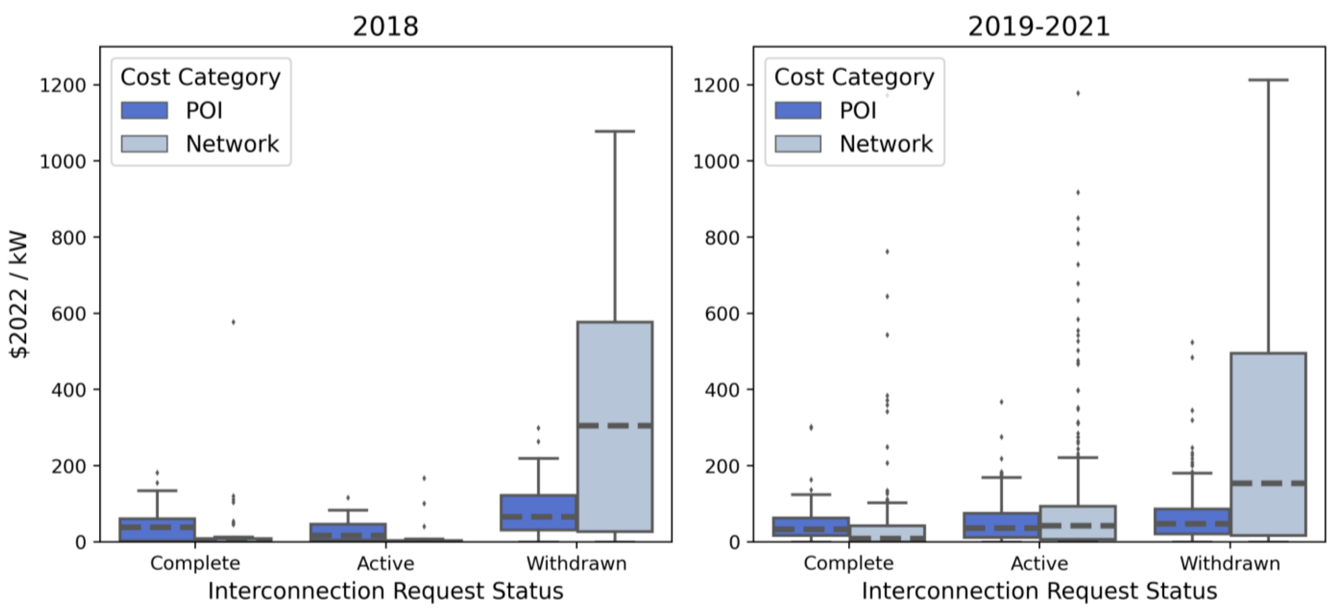

Figure 10 Interconnection Costs by Request Status and Cost Category *(not all outliers outside 1.5x interquartile range are shown)*

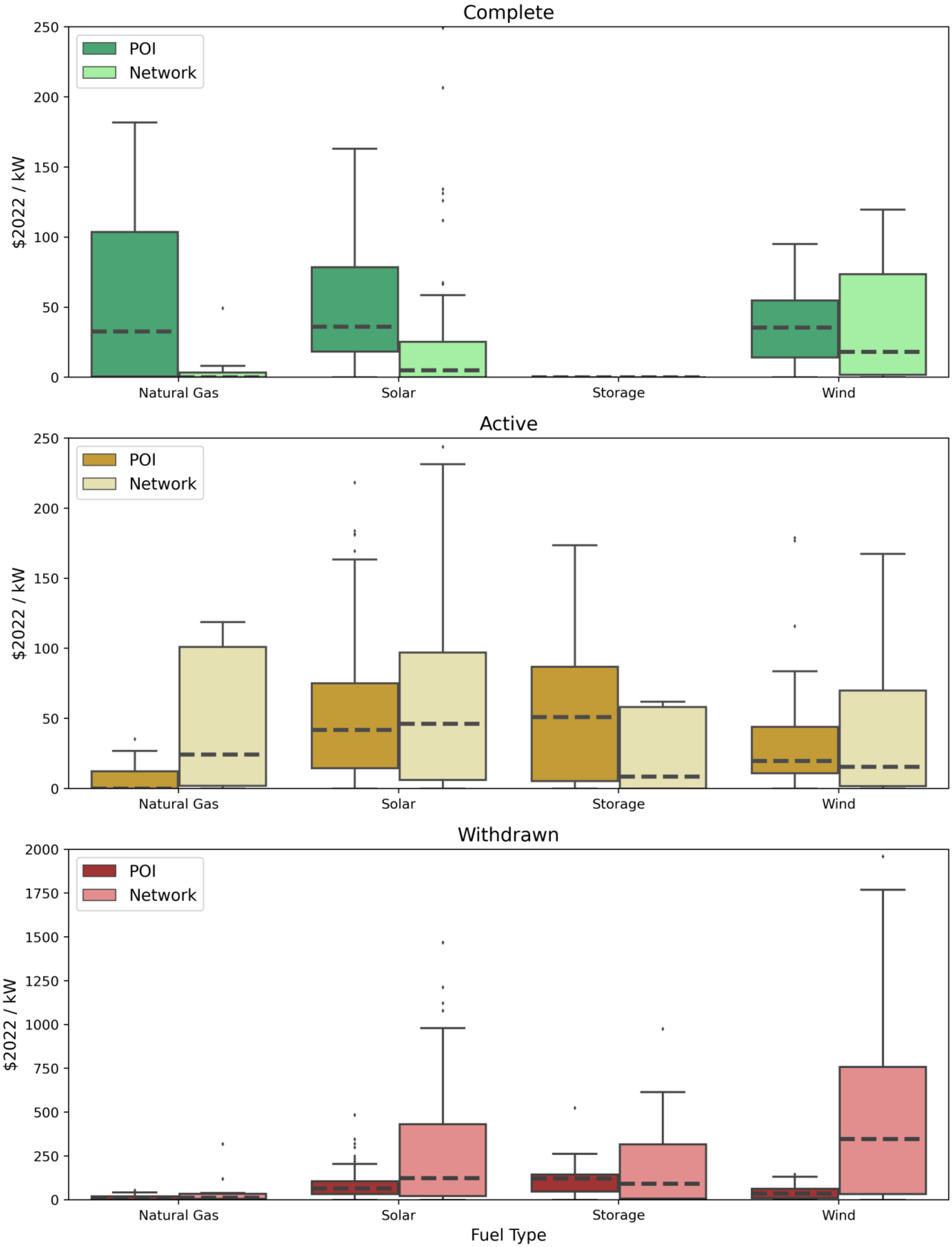

Figure 11 Interconnection Costs by Fuel Type, Request Status, and Cost Category *(2018-2021, not all outliers are shown)*

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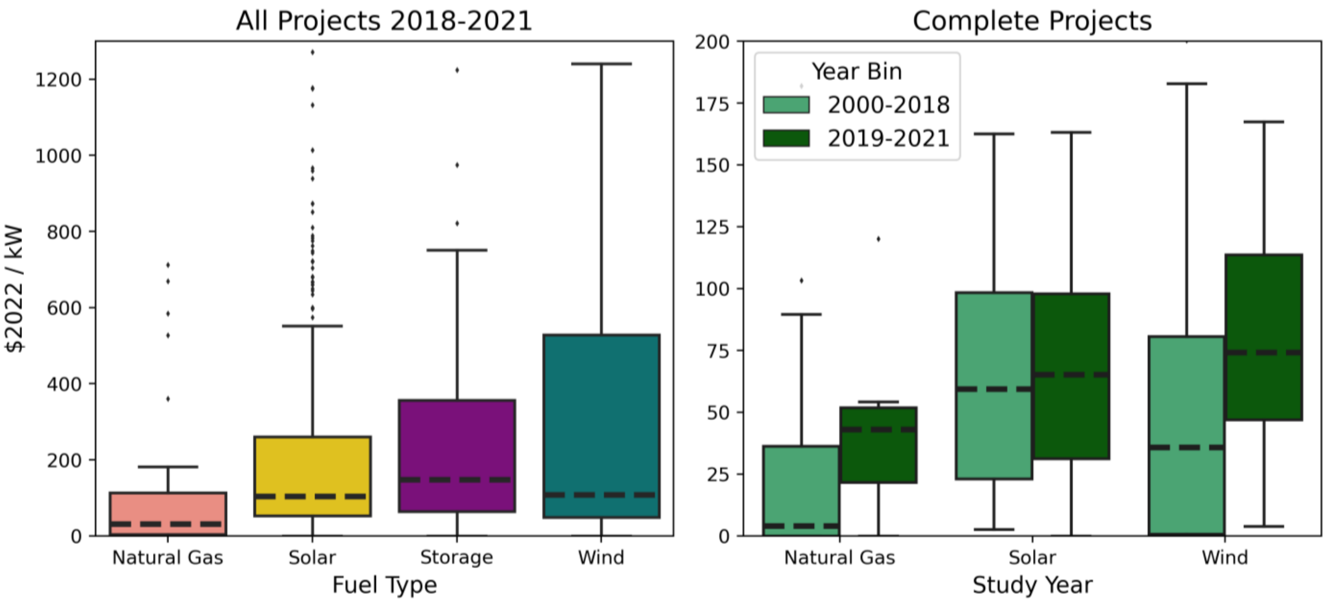

Figure 12 Interconnection Costs by Fuel Type (left) and Over Time for Complete Projects (right) *(not all outliers are shown)*

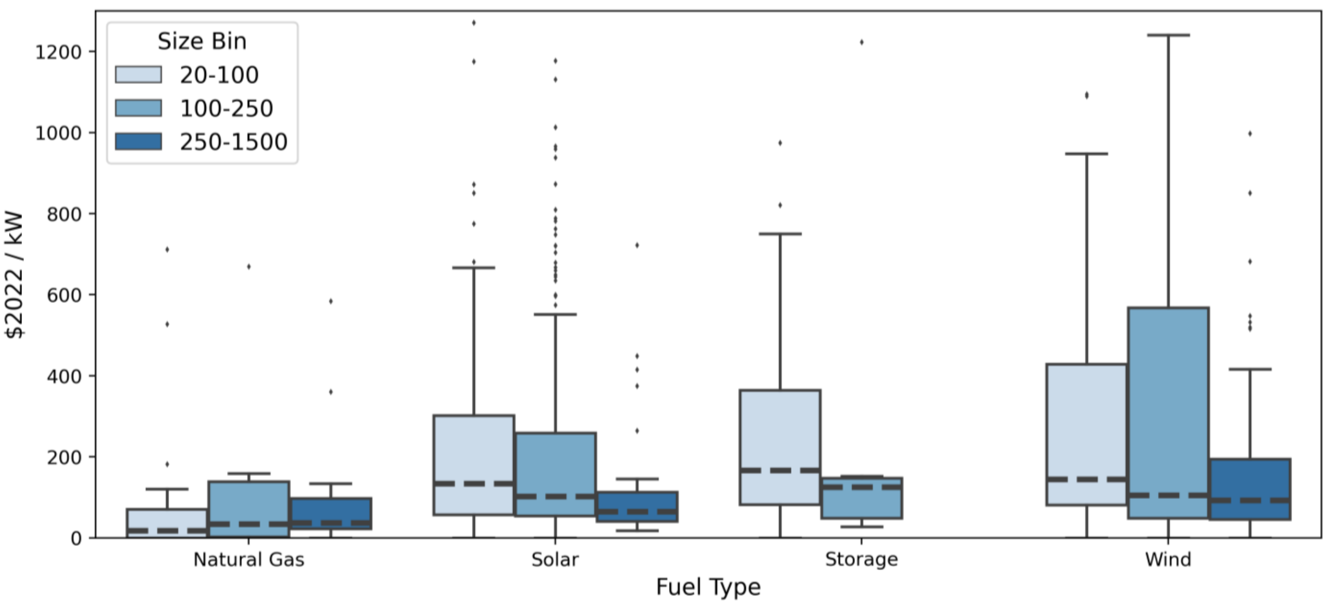

Figure 13 Interconnection Costs by Fuel Type and Size Bin *(2018-2021, not all outliers are shown)*

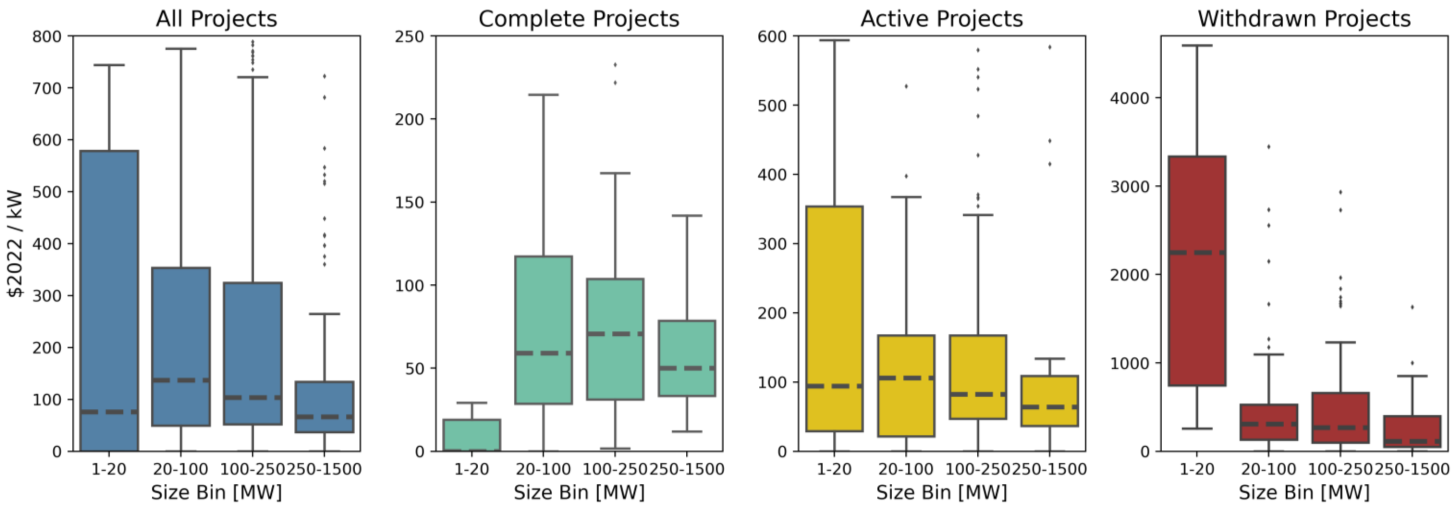

Figure 14 Total Interconnection Costs Request Status and Size Bin *(2018-2021, not all outliers are shown)*

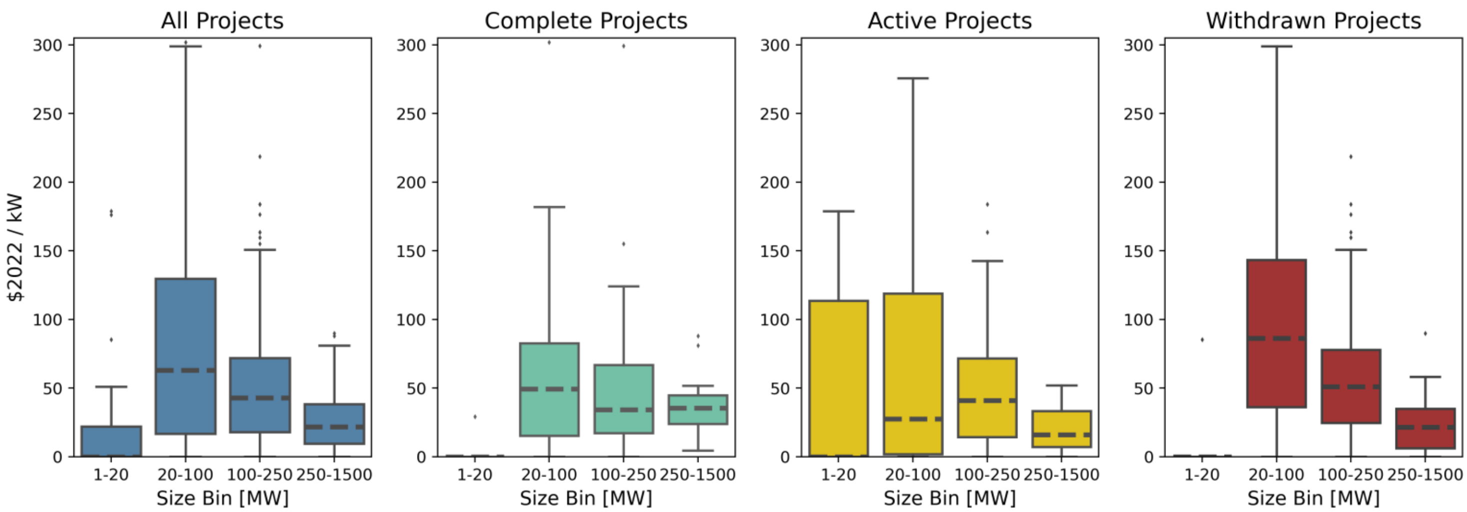

Figure 15 POI Interconnection Costs Request Status and Size Bin *(2018-2021, not all outliers are shown)*

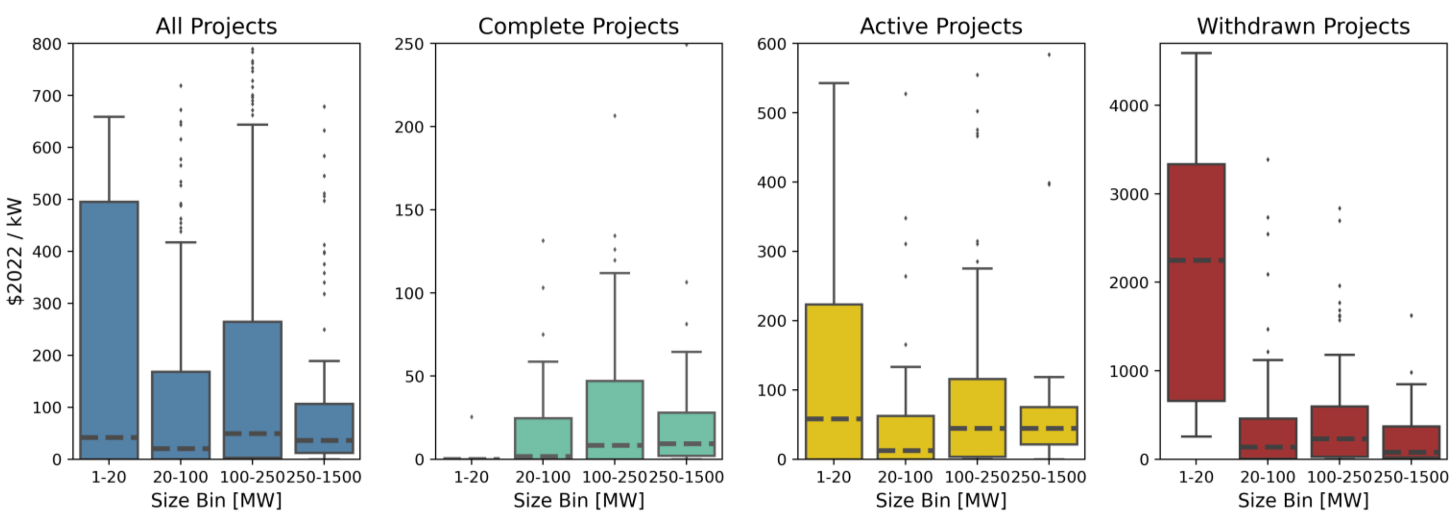

Figure 16 Network Interconnection Costs Request Status and Size Bin *(2018-2021, not all outliers are shown)*

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