Interconnection Cost Analysis in the PJM Territory

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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 PJM, the cumulative capacity of projects actively seeking interconnection more than doubled from 2019 through 2022. Based on available data on project-level interconnection costs from PJM, our analysis finds:

- **Project-specific interconnection costs can differ widely**, depending on many variables and do not have the shape of a normal distribution. For example, 95% of projects that have completed all required interconnection studies ("complete") between 2020 and 2022 have costs under $200/kW, but 5 projects cluster around $400/kW and one project has interconnection costs of $3,728/kW. At the same time, 30% of this sample even have costs under $5/kW.
- **Average Interconnection costs have grown**. Costs for recent "complete" projects have doubled on average relative to costs from 2000-2019 (mean: $42 to $84/kW, median: $18 to $30/kW). For projects still actively moving through the queue ("active"), mean costs have grown even more in recent years, from $29/kW to $240/kW (2017-2019 vs. 2020-2022, median: $8 to $85/kW). Interconnection requests that ultimately withdraw from the queue ("withdrawn") face the highest costs (mean: $599/kW, median: $244/kW)—likely a key driver for those withdrawals.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.** Mean costs for local attachment facilities at the point of interconnection (POI) are similar for complete ($12/kW), active ($13/kW), and historical withdrawn projects ($15/kW), although POI costs have recently increased for projects that ultimately withdraw ($36/kW). Costs for broader network upgrades beyond the interconnecting substation explain most cost differences and have risen sharply since 2019, to $71/kW for complete projects and $227/kW for active projects. Among withdrawn projects, they make up 94% of the costs at $563/kW for recent projects.
- **Potential interconnection costs of storage ($335/kW), solar ($253/kW), and wind ($136/kW for onshore, $385/kW for offshore) have been greater than natural gas ($24/kW) projects in recent years** (2017-2022). Among completed projects recent interconnection costs for solar ($99/kW) and onshore wind ($60/kW) have increased compared to historical costs (2000-2016), while natural gas costs have decreased ($18/kW). Costs for active and withdrawn storage and solar hybrid projects are surprisingly high ($337/kW), but complete projects are much cheaper (storage: $4/kW, solar hybrid: $20/kW). Solar projects that ultimately withdraw had interconnection costs of $559/kW (equivalent to 36% of total project installed costs), compared with $267/kW (or 19%) for withdrawn onshore wind applicants.
- **Larger generators have greater interconnection costs in absolute terms, but economies of scale exist on a per kW basis.** Among all potential projects, costs fall from $292/kW for medium-sized projects to $230/kW for large and $80/kW for very large project sizes. The size efficiencies generally hold for POI and network costs, and across request types (complete, active, withdrawn). When accounting for fuel type, economies of scale seem limited to natural gas, solar, and onshore wind, and to complete projects only.
- **Interconnection costs vary by location**, with projects in the western part of PJM (Michigan and West Virginia) reporting lower costs irrespective of request status ($36-56/kW). Applicants in the east where available transmission capacity is more limited (North Carolina, New Jersey, and Delaware) have higher costs ($485-971/kW).

The cost sample analyzed here represents 86% of all new unique generators requesting interconnection in PJM from 2000 to 2022. While it is sufficiently robust for detailed analysis, much data is difficult to obtain for 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.

1. The interconnection queue more than doubled in capacity since 2019

At year-end 2021, PJM had 259 gigawatts (GW) of generation and storage capacity actively seeking grid interconnection. Capacity in PJM's queue is dominated by solar (116 GW) and, to a lesser extent, standalone battery storage (42 GW), solar-battery hybrids (32 GW), and wind (39 GW). PJM's queue also contains data for projects no longer seeking interconnection, both those that are in service (79 GW) and those whose applications have been withdrawn (432 GW) (Rand et al. 2022). PJM's queue has ballooned in recent years, with 2021's active queue increasing by 240% compared to year-end 2019. The capacity associated with interconnection requests is nearly twice as large as PJM's peak load in recent years (~155 GW) and, if a substantial share is built, it will likely exert competitive pressure on existing generation. But historically, most projects withdraw: only 27% of projects requesting interconnection from 2000 to 2016 achieved commercial operation by year-end 2021.

Since 2012, PJM has implemented numerous reforms to reduce delays and project cancellations, including queue cluster extensions (to avoid queue study overlap and associated restudies) and an alternate queue for projects under 20 MW (which had high withdrawal rates) (Caspary et al. 2021). In 2021, following the large increase in interconnection requests and multiple interconnection process workshops, PJM embarked on a queue reform that was recently approved by FERC (FERC 2022). The core changes aim at a faster and more efficient interconnection process with greater cost certainty. They include a clustered, "first-ready, first-serve" approach, size-based study deposits, and increased readiness deposits that are at risk when projects withdraw later in the study process. In an effort to clear the existing request backlog, PJM will adopt an "expedited process" for a transitional period, allowing projects with network upgrades under $5 million to be studied in a fast track. Going forward, projects that do not contribute to the need for network upgrades will be able to proceed quicker to a final interconnection agreement under "accelerated procedures" (PJM 2022b). PJM also launched a new public tool (QueueScope) in 2022 to facilitate the assessment of grid impacts of proposed generation before submitting interconnection requests, but information is limited to line loading changes and does not include potential upgrade costs (PJM 2022e).

2. Cost sample represents 86% of new generators requesting interconnection over the past decade

This brief analyzes generator interconnection cost data from 1,127 projects that were evaluated in interconnection studies between 2000 and 2022, equivalent to 86% of all new unique generators over that time period.

Our interconnection cost sample has two sources:

- All cost data that were accessible in the online PJM system as of July 2022: 1,072 projects (PJM 2022a).
- Cost data for 55 additional projects that were collected in 2018 and had since been removed from the online PJM system (Gorman, Mills, and Wiser 2019).

While the sample is sufficiently robust to enable detailed analysis of interconnection costs, it represents only a subset of the 7,419 projects that are listed in the queue. We a) focus on new generation facilities (excluding 1,101 projects that represent capacity upgrades to existing facilities); b) require at least a posting of a feasibility study (excluding 3,134 projects without such a study); and c) remove superseded queue projects that withdraw and later reapply (excluding 1,772 projects, see left panel in Figure 1). We were not able to analyze costs for projects entering the queue after March 2021, as insufficient time had elapsed for their associated interconnection studies and cost estimates to be completed. PJM interconnection cost data is accessible without "Critical Energy Infrastructure Information" (CEII) certification, and cost excerpts are posted in part online (PJM 2022d). However, for the purposes of this analysis it still required manual cost extraction from study pdfs averaging 30-50 minutes per project, equivalent to about 550 hours for the entire sample. 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 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 via a system impact study to a refined facility study.

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

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 (373 projects, 56.8 GW). Some projects ultimately withdraw from the interconnection process for a variety of reasons; our data includes 189 such projects (21.7 GW) that were studied mostly between 2018 and 2022. Projects that are still active in the interconnection study process were primarily evaluated between 2020 and 2022 (565 projects, 59.4 GW).

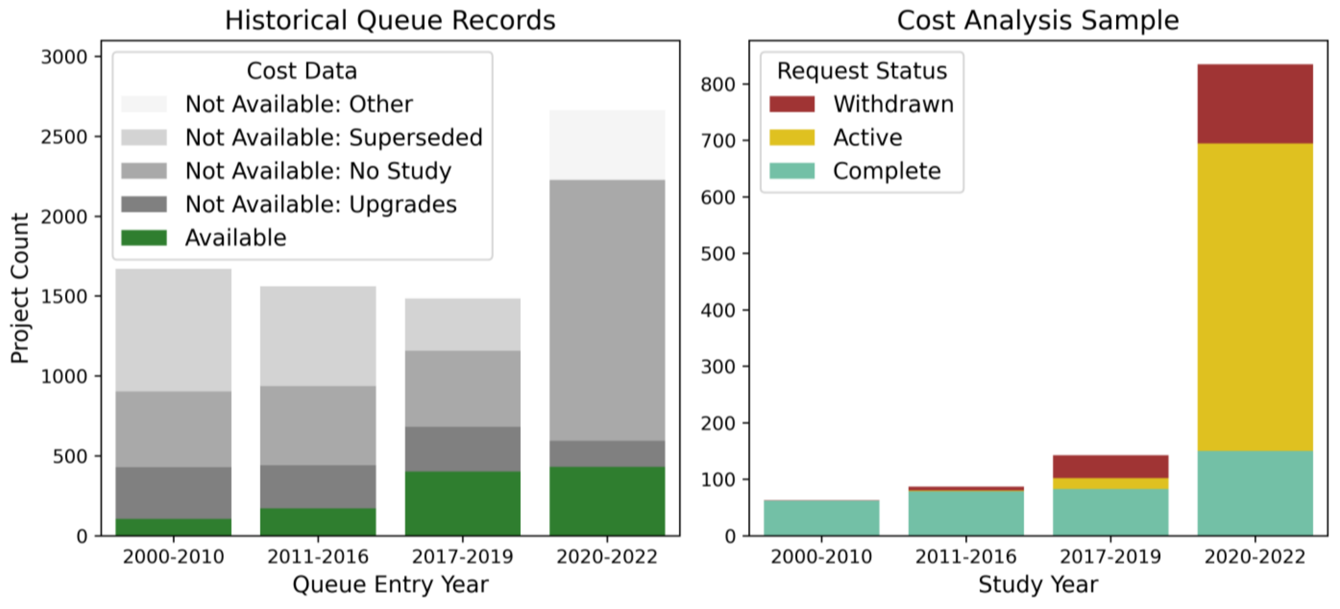

Figure 1 Sample: Availability of Cost Data Relative to Historical Queue Records *(left)*, **and Cost Data by Request Status** *(right). The left graph shows all historical generators seeking interconnection, indexed by their queue entry year. The right graph represents our cost analysis sample, with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

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, facility studies and interconnection agreements). 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 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 2017 and 2022. The histogram shows that more than 95% of all projects in this sample have interconnection costs under \$200/kW, but five projects cluster around \$400/kW (Figure 2, left), and two have costs of \$712/kW and \$3,728/kW (not shown). Medians (shown as dashed lines in the center of the boxplot) describe a "typical" project, with costs of \$24/kW, but individual cost components cannot be added to meaningful sums. Means (Figure 2, right) can be influenced by a small number of projects with very high costs and are often higher than medians (\$73/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.

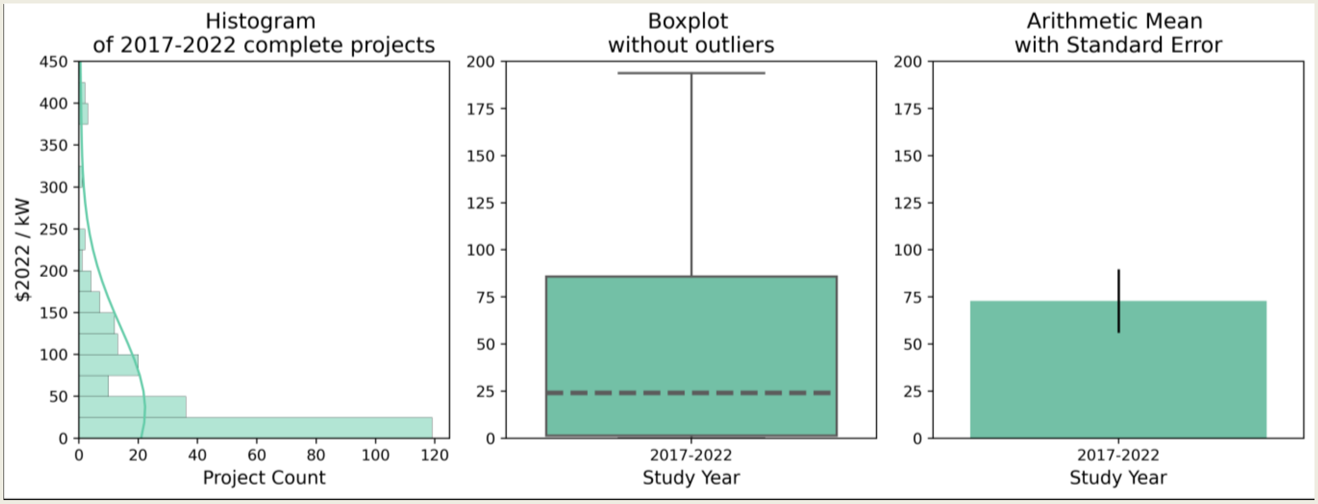

Figure 2 Interconnection Cost Metrics Example: Subsample of Projects Completing the Study Process, 2017-2022

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.

3.1 Average interconnection costs have grown over time

Potential interconnection costs across all applicants increase in our sample after 2000. But combining all projects regardless of request status is problematic. Our cost sample composition changes over time, containing mainly completed projects in the early years but greater 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 projects with <u>completed</u> interconnection studies, interconnection costs double from $42/kW before 2020 to $84/kW between 2020 and 2022 (the standard error of the mean $\hat{\sigma}_{\bar{x}}$ $5/kW and $26/kW respectively). Projects that were still <u>actively</u> moving through the interconnection queues saw costs increase eightfold, from $29/kW to $240/kW (2017-2019 vs. 2020-2022, $\hat{\sigma}_{\bar{x}}$=9&23). Projects that ultimately <u>withdraw</u> have seen costs more than double, from $255/kW to $599/kW (2017-2019 vs. 2020-2022, $\hat{\sigma}_{\bar{x}}$=187&103).[1] Costs for withdrawn projects are more than seven times the costs of "complete" projects between 2017 and 2022 ($521/kW vs. $73/kW, $\hat{\sigma}_{\bar{x}}$=91&17).[2]

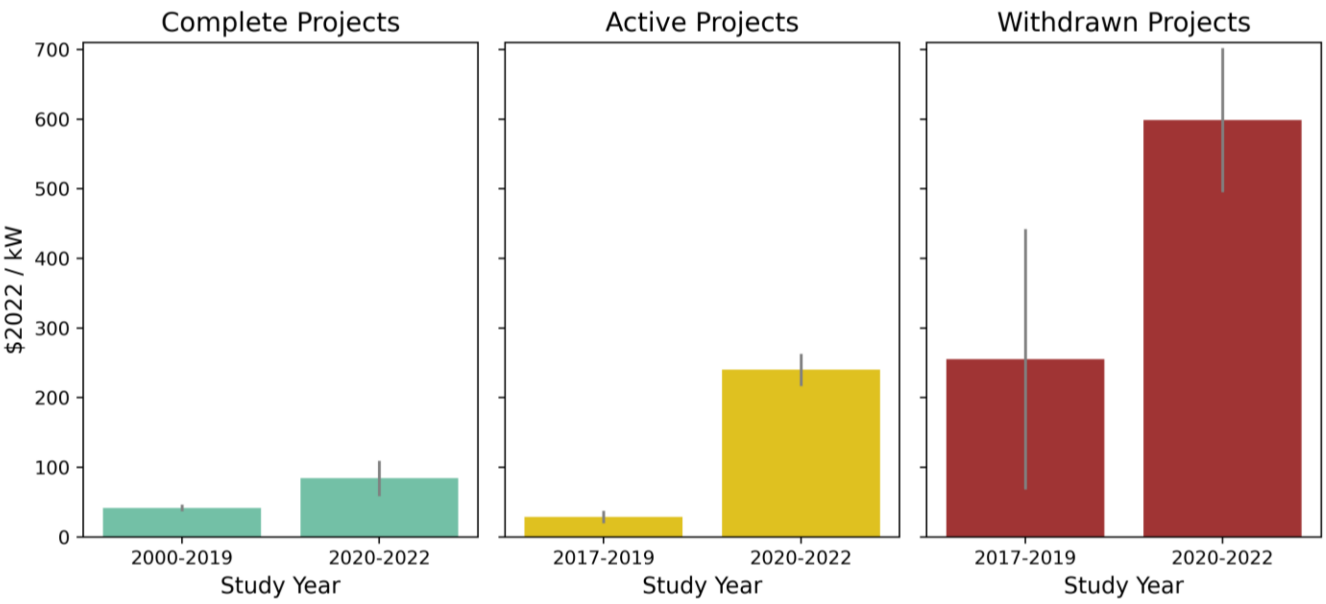

Figure 3 Interconnection Costs over Time by Request Status *(bars show simple means, gray lines represent standard error)*

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 costs describing investments at the point of interconnection (POI) with the broader transmission system. The FERC pro-forma Large Generator Interconnection Agreement (LGIA) refers to them as "Interconnection Facilities," while our study calls them POI costs.[3]

(2) Broader network upgrade costs.[4]

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[1] Median costs nearly double for completed projects ($18 to $30/kW), grow eightfold for active projects ($8 to $85/kW), and increase by a factor of fourteen for withdrawn projects ($17 to $244/kW).

[2] Median costs for withdrawn projects are also more than six times the costs of complete projects over the period 2017-2022 ($156 vs. $24/kW).

[3] POI (Interconnection Facilities) 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. This category is referred to as "Attachment Facilities" in PJM's interconnection studies.

[4] Network costs refer to two broad categories: Network Upgrade Charges (consisting of estimates for "Direct Connection Facilities," "Total Direct Connect Costs," "Direct Connection Network Upgrades," "Total Non-Direct Connection Costs," "Network Upgrade Facilities," "Non Direct Connection Facilities," and "Non Direct Connection Network Upgrades") and Other Network Costs (consisting of estimates for "Non-Direct Local Network Upgrades," "Allocation for New System Upgrades" (or System Network Upgrades), "Contribution for Previously Identified Upgrades," and "Other Charges").

Among the projects that successfully <u>complete</u> all interconnection studies, local upgrades at the POI are modest in PJM, accounting for only \$12/kW (2017-2022, $\hat{\sigma}_{\bar{x}}=2$). In fact, POI costs have actually fallen by a few dollars since the early 2000s in this subsample. Network upgrade costs, on the other hand, can cause large cost additions for some projects and have grown in recent years (from \$42/kW in 2017-2019 to \$71/kW in 2020-2022, $\hat{\sigma}_{\bar{x}}=10\&25$, Figure 4).[5]

Projects still being <u>actively</u> evaluated have similarly low POI costs that have remained stable at \$13/kW in recent years ($\hat{\sigma}_{\bar{x}}=1$, Figure 4). However, network costs are the real cost driver: they are greater compared to completed projects in 2020-2022, again featuring in some projects with very high costs, and have risen in recent years from an average of \$15/kW in 2017-2019 to \$227/kW in 2020-2022 ($\hat{\sigma}_{\bar{x}}=6\&23$, Figure 4).[6]

The situation is somewhat different for projects that ultimately <u>withdraw</u> from the interconnection process. POI costs were similar to active and complete projects in 2017-2019 at \$15/kW ($\hat{\sigma}_{\bar{x}}=4$), but have more than doubled to \$36/kW in 2020-2022 ($\hat{\sigma}_{\bar{x}}=13$). The required network upgrades are again what set the withdrawn projects apart: they doubled from an already high \$240/kW to \$563/kW ($\hat{\sigma}_{\bar{x}}=185\&103$, Figure 4). The top 10% of network upgrade costs range between \$928/kW and \$10,164/kW.[7]

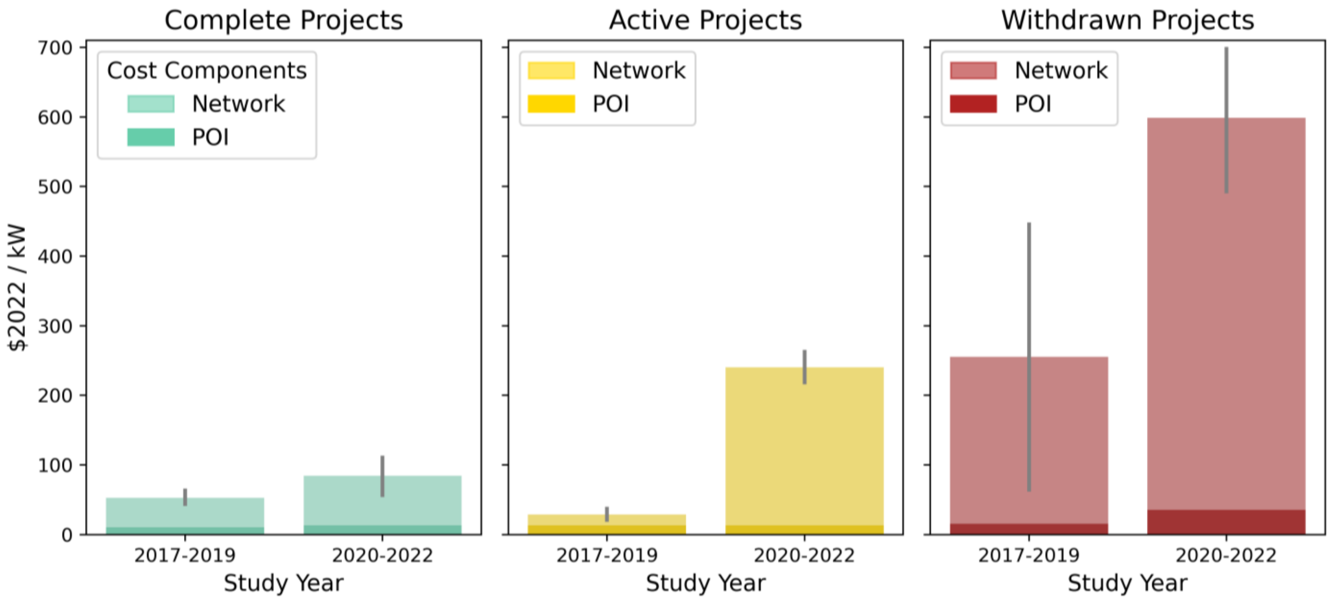

Figure 4 Interconnection Costs by Cost Category and Request Status *(bars: means, gray lines: standard error of total costs)*

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 solar (649), solar-battery hybrid (131), storage (114), natural gas (105), onshore wind (88), and offshore wind (11) projects, but also some hydropower (9), biomass (6), oil (4), coal (3), and nuclear (2) plants.

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[5] For complete projects in 2017-2022, median POI costs are \$3/kW, median network costs are \$16/kW (see also Figure 11 in the Appendix).

[6] For active projects in 2017-2022, median POI costs are \$7/kW, median network costs are \$68/kW (see also Figure 11 in the Appendix).

[7] For withdrawn projects in 2017-2022, median POI costs are \$10/kW, median network costs are \$136/kW (see Figure 11 in the Appendix). See, for example, a system impact study proposing upgrade costs of almost \$599 million for a 51 MW solar project: https://www.pjm.com/pub/planning/project-queues/impact_studies/ag1129_imp.pdf

Offshore wind ($385/kW), storage ($335/kW), solar hybrid ($267/kW), solar ($253/kW), and onshore wind ($136/kW) costs are greater than natural gas ($24/kW) costs when looking at all recent projects, irrespective of their request status (see Figure 5, left).[8] High costs for storage and solar hybrid applicants seem surprising at first, as their operational flexibility should enable such projects to respond to transmission constraints if dispatched in response to local grid needs. But it appears that, despite storage's locational flexibility, many prospective projects have been proposed in regions with high transmission line loadings. Larger interconnection costs for batteries may also reflect a premium to qualify capacity in the PJM market, which assumes maximum storage discharge during peak load conditions.

The sample offers the longest time record for projects that complete interconnection studies. Looking at projects studied before and after 2017, we find that natural gas interconnection costs fall from $40/kW to $18/kW ($\hat{\sigma}_{\bar{x}}$=8&5). Costs grow for renewables: average solar costs increase from $54/kW to $99/kW ($\hat{\sigma}_{\bar{x}}$=12&26), whereas onshore wind costs rise from $23/kW to $60/kW ($\hat{\sigma}_{\bar{x}}$=5&29, see right panel in Figure 5). We only have solar hybrid projects with completed studies after 2020, but this subset seems to have much lower costs at $20/kW ($\hat{\sigma}_{\bar{x}}$=12) compared to stand-alone solar. The storage sample is small (2012-2016: n=4, 2017-2022: n=7), but average costs seem to have declined from $19/kW to $4/kW ($\hat{\sigma}_{\bar{x}}$=11&4), are much lower than for all proposed storage projects (including active and withdrawn ones), and are even lower than for natural gas.[9]

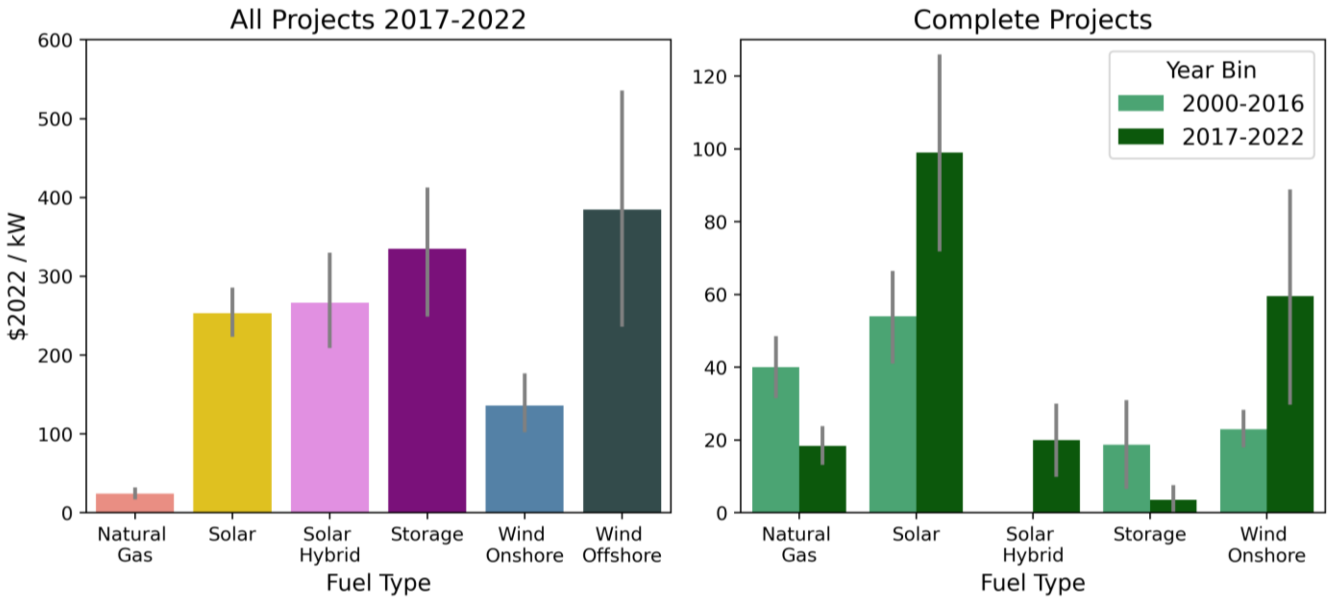

Figure 5 Interconnection Costs by Fuel Type (left) and Over Time for Complete Projects (right) *(bars: means, gray lines: standard error)*

For renewables that complete the study process, interconnection costs represent about 4% of total wind project installation costs in PJM (Wiser et al. 2022) compared to 7% of overall solar project installation costs in PJM in 2021 (Bolinger et al. 2022). Interconnection cost burdens are thus similar to those in MISO for solar (also 7%), but much less for wind (16% in MISO) (Seel et al. 2022). One potential driver of the larger

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[8] $\hat{\sigma}_{\bar{x}}$ = 160, 78, 61, 28, and 34. The same trend is evident if we examine median interconnection costs for offshore wind ($190/kW), solar hybrid ($82/kW), solar ($82/kW), storage ($63/kW), and onshore wind ($46/kW) vs. natural gas ($8/kW), see Figure 13 in the Appendix.

[9] In median terms, the cost difference is less pronounced but the same trends hold: natural gas interconnection costs fall from $11/kW to $8/kW, solar costs grow from $33/kW to $43/kW, and onshore wind costs rise from $14/kW to $22/kW. The median solar hybrid costs are $0/kW for both year bins, for standalone storage they fall from $14/kW to $0/kW.

interconnection costs for wind and solar may be siting differences, as renewable generators are typically located in more rural areas with fewer nearby substations.

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 2017-2022 sample. POI costs do not vary much by request status, except for rather low costs for complete wind projects ($3/kW) and unusually high costs for withdrawn solar projects ($39/kW). The average POI costs across the entire 2017-2022 sample is $16/kW.

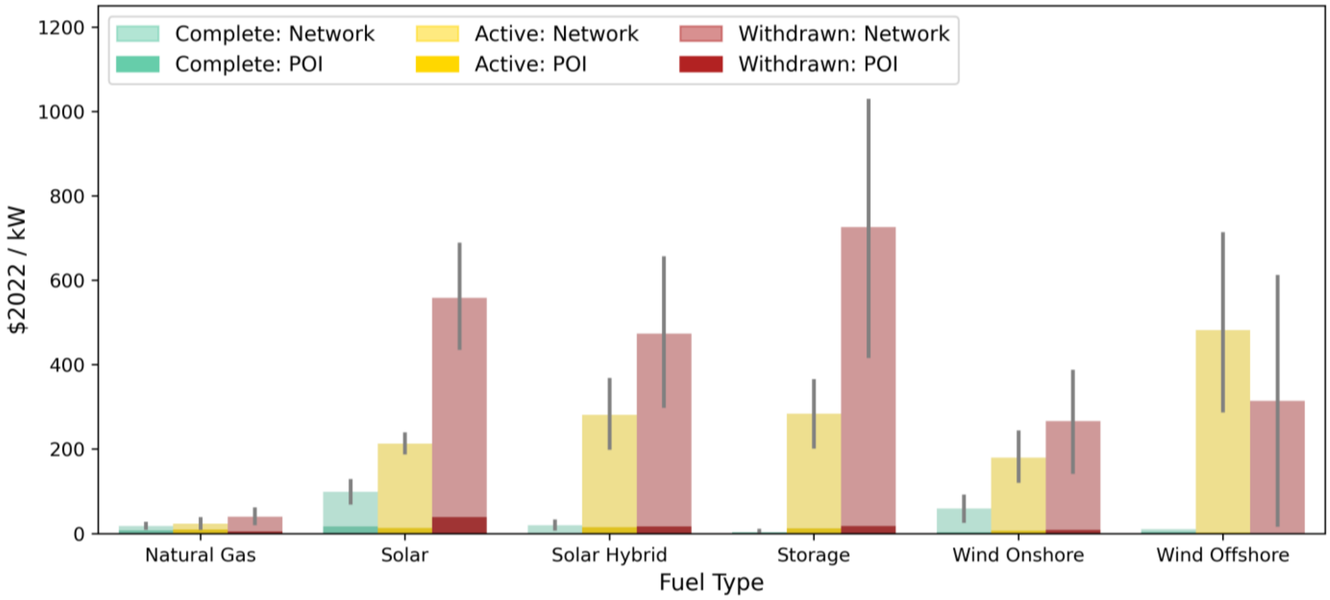

Figure 6 Interconnection Costs by Fuel Type, Cost Category, Request Status *(bars: means, gray lines: standard error of total costs, 2017-2022)*

In contrast, network costs increase dramatically for <u>active</u> and <u>withdrawn</u> projects relative to those that completed all studies. Completed storage projects had no network upgrade costs (n=7), while the average costs for withdrawn projects was $709/kW (n=17). Network costs were 25 times greater for withdrawn solar hybrid projects relative to complete projects ($457/kW vs. $18/kW). Withdrawn solar projects had six times greater network costs than complete projects ($520/kW vs. $82/kW), and withdrawn onshore wind projects had nearly five times the network costs of complete projects ($258/kW vs $56/kW).[10] The costs for "complete" offshore wind projects may not be representative, consisting of only one project, with data on active and withdrawn offshore wind projects showing relatively high costs of $482/kW and $315/kW, respectively.

High total interconnection costs among withdrawn solar projects of $559/kW ($\hat{\sigma}_{\bar{x}}$=124, or 38% of overall project installation costs (Bolinger et al. 2022)) may explain why some solar projects abandon the queue. Total interconnection costs of withdrawing wind projects are lower at $267/kW ($\hat{\sigma}_{\bar{x}}$=126), but would still account for 19% of installed project costs (Wiser et al. 2022).

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[10] $\hat{\sigma}_{\bar{x}}$ of network costs for solar hybrid are 177 (withdrawn) & 9 (complete), for solar 123 & 25, and for onshore wind 128 & 29.

3.4 While larger generators have greater absolute costs, economies of scale exist on a per kW basis

Projects with larger nameplate capacity ratings have greater average interconnection costs in absolute terms. Between 2017 and 2022, all potential projects smaller than 20 MW have average costs of $2 million, which compares to $12 million for medium-sized projects (20-100 MW), $41 million for large (100-500 MW), and $65 million for very large (500-1750 MW) projects.

But these costs do not scale linearly on a per kW basis. Costs fall from $292/kW for medium projects to $230/kW for large and $80/kW for very large project sizes, respectively, suggesting economies of scale. Small projects have slightly lower average costs at $202/kW.[11] 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 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 request statuses (see Figure 7). Very small projects again seem to have lower total interconnection costs. Medium-sized projects have usually the largest costs ($107/kW for complete, $246/kW for active and $660 for withdrawn projects) and the largest projects have only one-third to one-seventh of those costs.

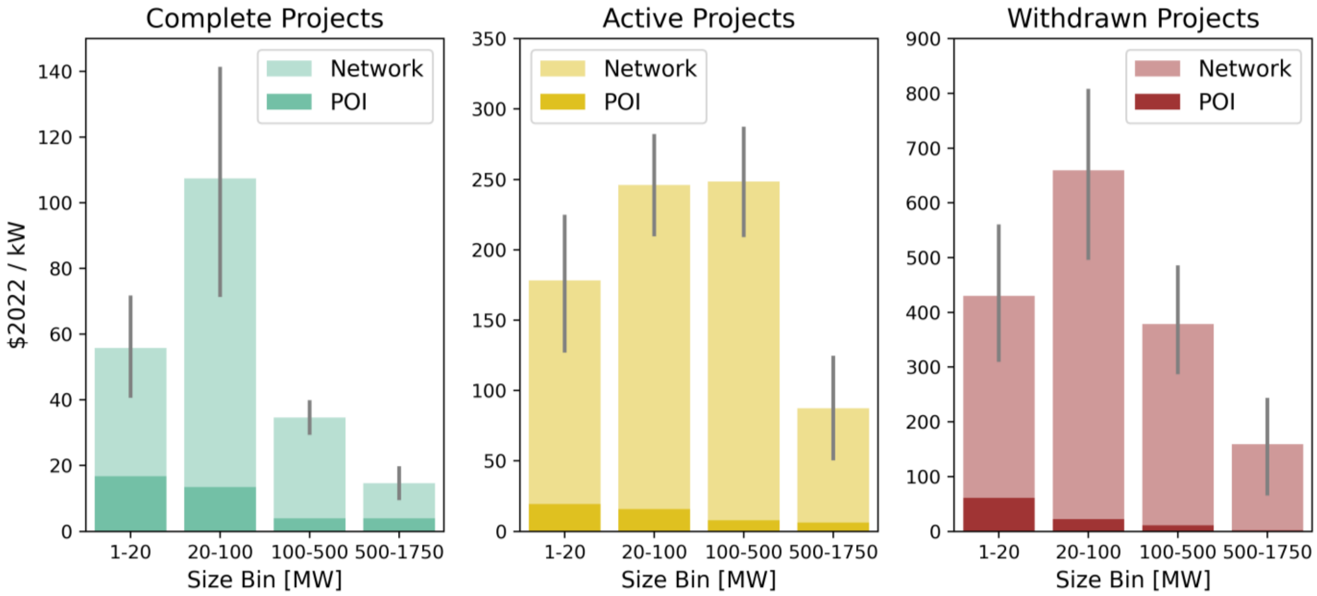

Figure 7 Interconnection Costs by Capacity and Request Status *(bars: means, gray lines: standard error of total costs, 2017-2022, y-axes differ by panel)*

Economies of scale do not hold consistently when accounting for fuel type, especially among withdrawn and active projects (see Appendix, Figure 14). Focusing only on complete projects, however, we find some evidence of declining costs with increasing project size for natural gas, solar, and onshore wind projects.

Fuel	1-20 MW	200-100 MW	100-500 MW	500-1750 MW
Natural Gas	$30/kW		$15/kW	$15/kW
Solar	$81/kW	$123/kW	$45/kW	$14/kW
Onshore Wind	$712/kW	$37/kW	$24/kW	

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[11] $\hat{\sigma}_{\bar{x}}$ across size bins are 40 for small, 38 for medium, 31 for large, and 26 for very large projects. Median costs are $38/kW for small, $90/kW for medium, $78/kW for large, and $11/kW for very large projects (see Figure 15 in the Appendix).

We can only compare longer time trends for the subsample that has completed the interconnection studies, but find that larger projects have generally had lower costs compared with their smaller counterparts since 2012, on a per-kW basis.

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 permits participation in the energy market and largely uses the existing transmission system on an as available basis.

The vast majority (95%) of all projects studied between 2017 and 2022 chose capacity as service type, a substantial increase over earlier years. Nearly all renewable projects opt for capacity status (wind offshore: 100%, solar: 99%, wind onshore: 98%) with the exception of solar hybrid projects (76%). Natural gas (95%) and storage (92%) stand-alone installations have slightly lower rates.

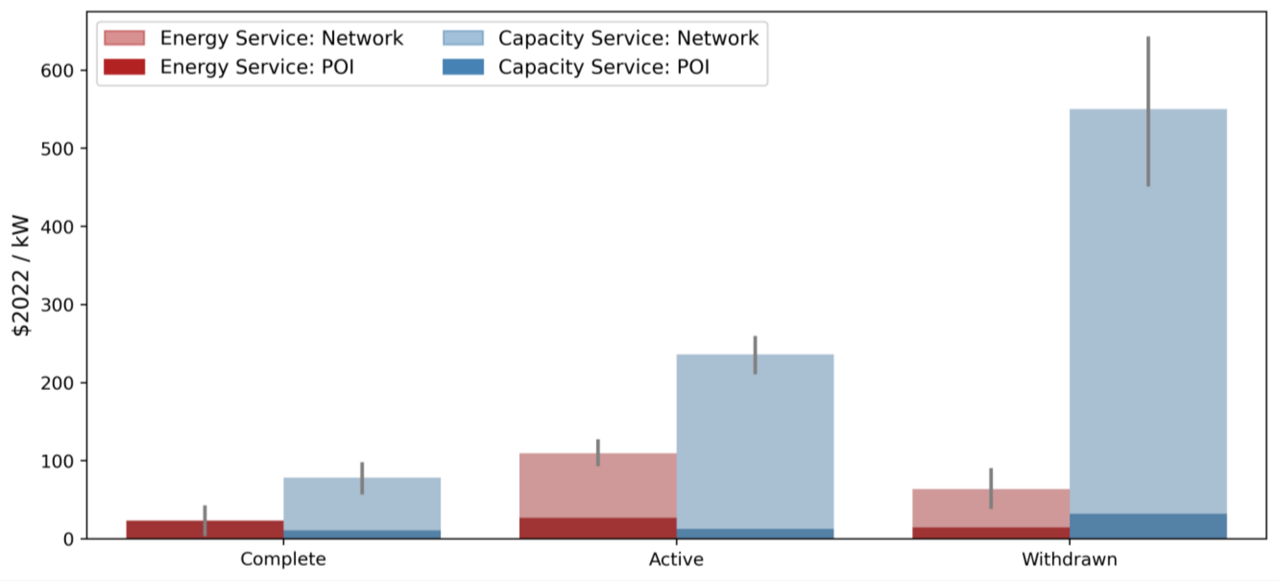

Figure 8 Costs by Service Type, Cost Category, Request Status *(bars: means, gray lines: standard error of total costs, 2017-2022)*

While POI costs are roughly similar, network upgrade costs are much higher for capacity than energy projects as one might expect, a trend that has increased in recent years. Capacity network costs across all request status were historically only slightly higher ($17/kW), but that differential grew to $206/kW between 2017 and 2022. Figure 8 inspects interconnection costs by request status and service type, and shows that among recent energy projects that complete all interconnection studies average network upgrade costs were $0/kW (compared with capacity: $67/kW). Energy projects that are still actively being evaluated are now assessed network upgrade costs of $83/kW (capacity: $223/kW), while withdrawn energy projects are billed $49/kW for network upgrades compared to $518/kW for withdrawn capacity projects.

3.5 Interconnection costs in eastern PJM states are generally higher than in the west

Interconnection costs also vary by location, with western projects in Michigan ($36/kW) and West Virginia ($58/kW) reporting overall lower costs across all projects studied between 2017 and 2022, irrespective of whether they ultimately complete the interconnection process. Eastern applicants in North Carolina, New Jersey, and Delaware, on the other hand, have high average interconnection costs ($485-971/kW). Overall, there is some alignment between states with high interconnection costs and states with little available transmission capacity and/or high levels of congestion, as indicated for example by higher zonal capacity prices (PJM 2022c), which tend to be located primarily in the eastern part of the ISO.

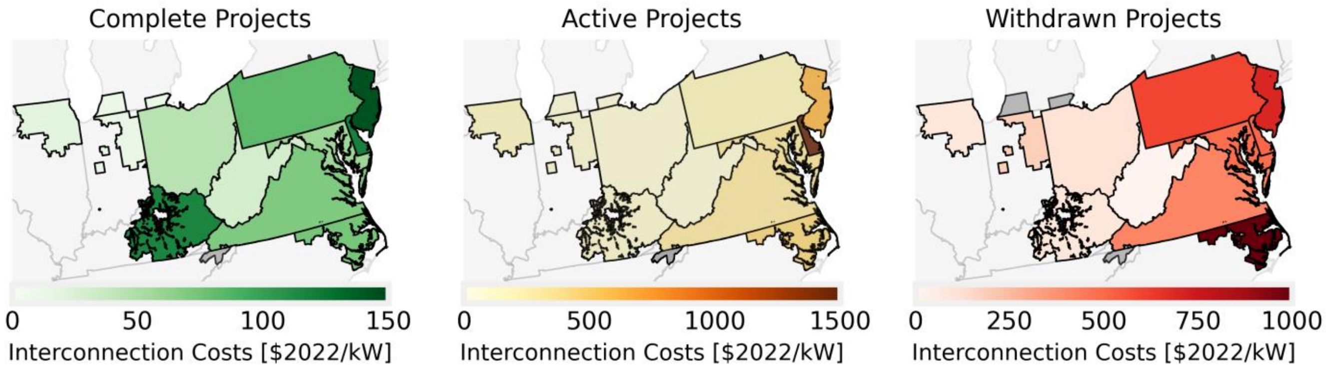

Figure 9 Interconnection Costs by State and Request Status, all Fuel Types *(means, 2017-2022, grey areas indicate no data)*

Figure 9 examines cost variation by state and project status request. Eastern states again have comparatively high interconnection costs among complete (New Jersey: $143/kW) and withdrawn projects (North Carolina: $1068/kW, New Jersey: $759/kW), while western states like Indiana and Illinois have lower costs for completed projects ($14/kW, $20/kW), as do Kentucky and Ohio for withdrawn projects ($88/kW, $108/kW). A seeming outlier is the high cost for completed projects in the west in Kentucky ($117/kW), but this is a small sample with only five observations consisting only of recent solar and solar hybrid projects interconnecting mostly to the small East Kentucky Power Cooperative.

Appendix Figure 18 to Figure 23 dive deeper into geographical cost distributions by fuel type, showing again higher interconnection costs in the east for solar, solar hybrid, and storage. Natural gas projects skew a bit differently, with higher costs both in the north (New Jersey, Ohio, and Pennsylvania) and south (Virginia). Onshore wind has higher costs in the north (New Jersey, Pennsylvania, and Illinois) than in the south. Delaware, New Jersey, and Virginia have higher interconnection costs for offshore wind than Ohio.

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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
For all of our downloadable publications, visit https://emp.lbl.gov/publications
To contact the corresponding author, email jseel@lbl.gov

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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, and 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 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).

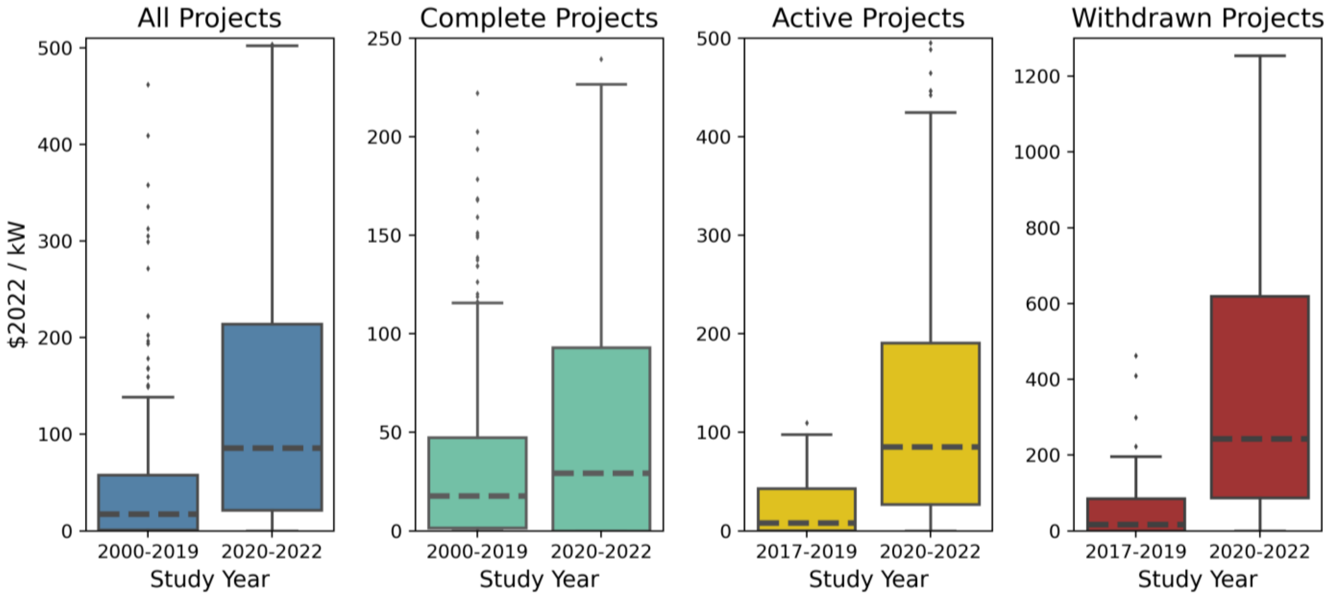

Figure 10 Interconnection Costs over Time by Request Status *(**y-axes differ by panel**, not all outliers outside 1.5x interquartile range are shown)*

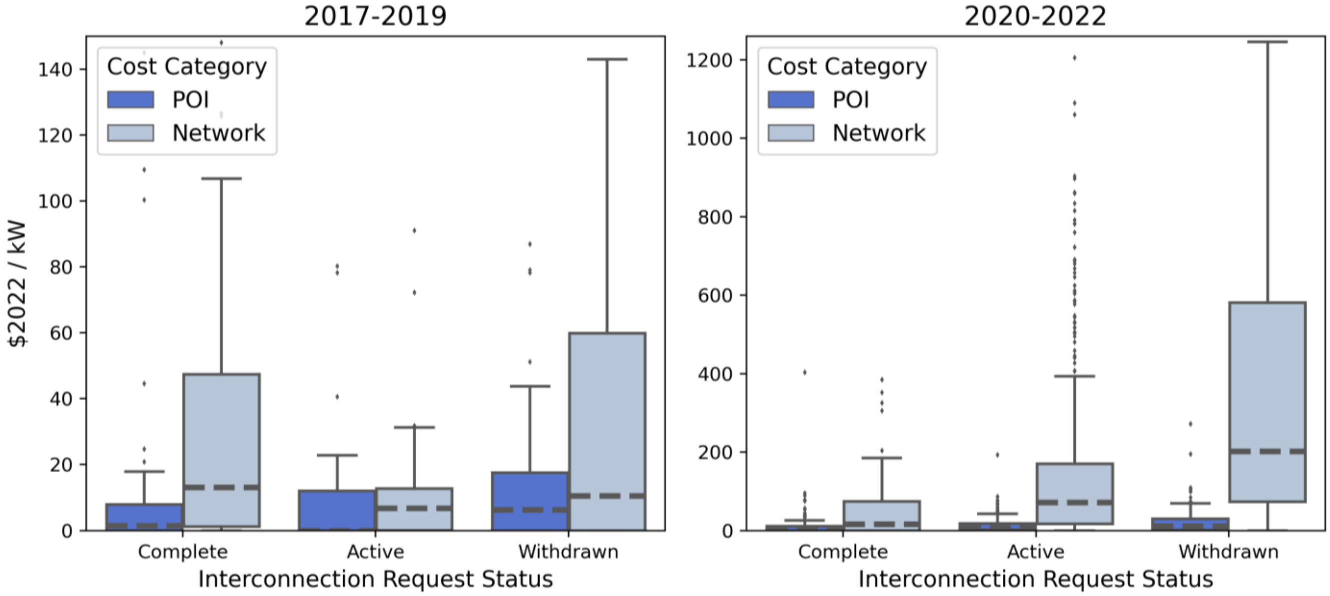

Figure 11 Interconnection Costs by Request Status and Cost Category *(**y-axes differ by panel**, not all outliers outside 1.5x interquartile range are shown)*

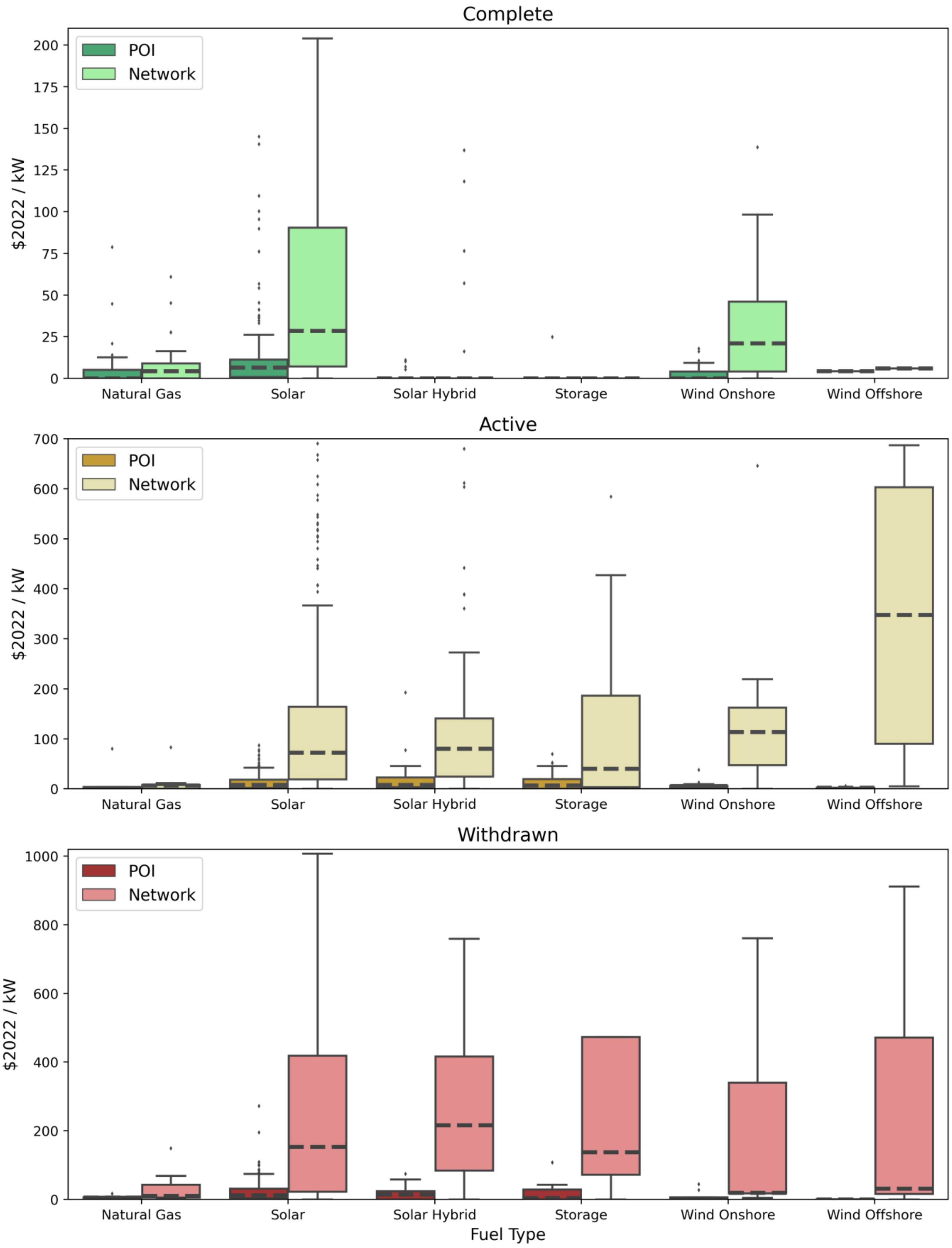

Figure 12 Interconnection Costs by Fuel Type, Request Status, and Cost Category *(**y-axes differ by panel**, 2017-2022, not all outliers are shown)*

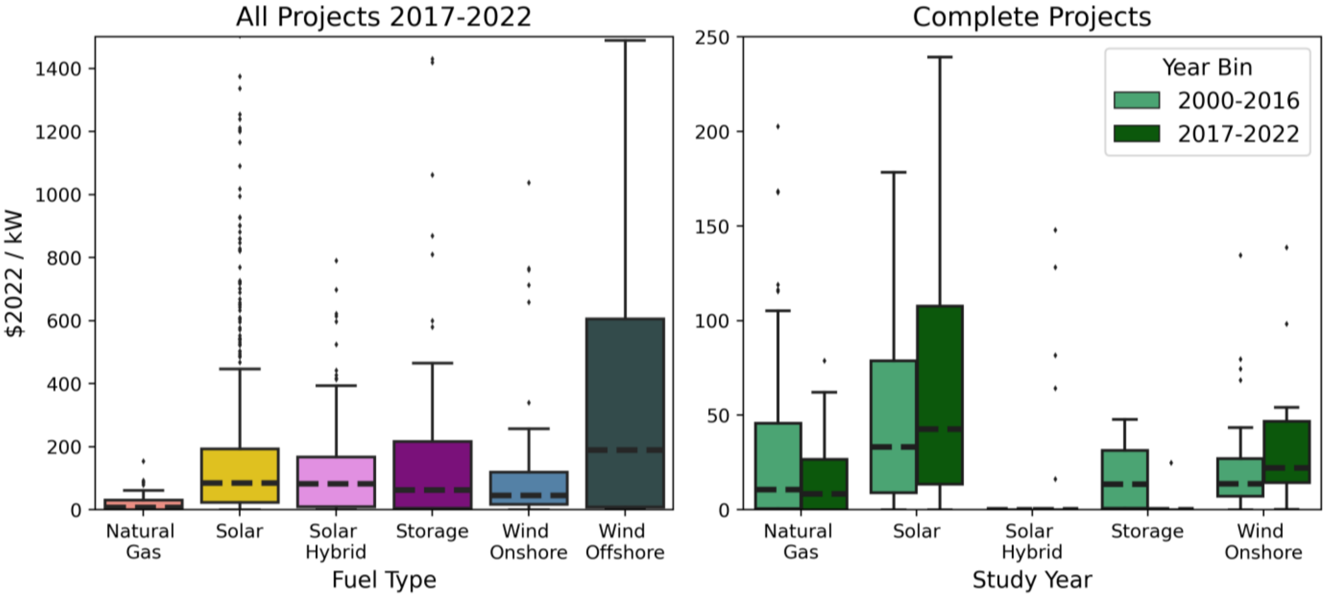

Figure 13 Interconnection Costs by Fuel Type (left) and Over Time for Complete Projects (right) *(**y-axes differ by panel**, not all outliers are shown)*

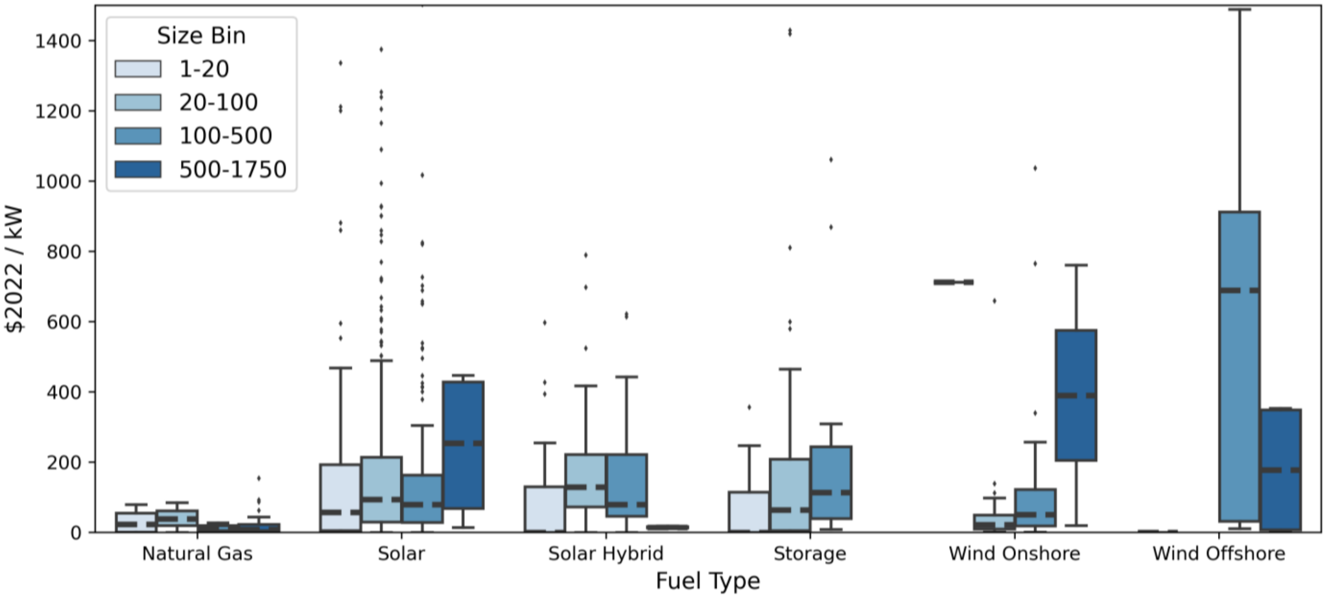

Figure 14 Interconnection Costs by Fuel Type and Size Bin *(2017-2022, not all outliers are shown)*

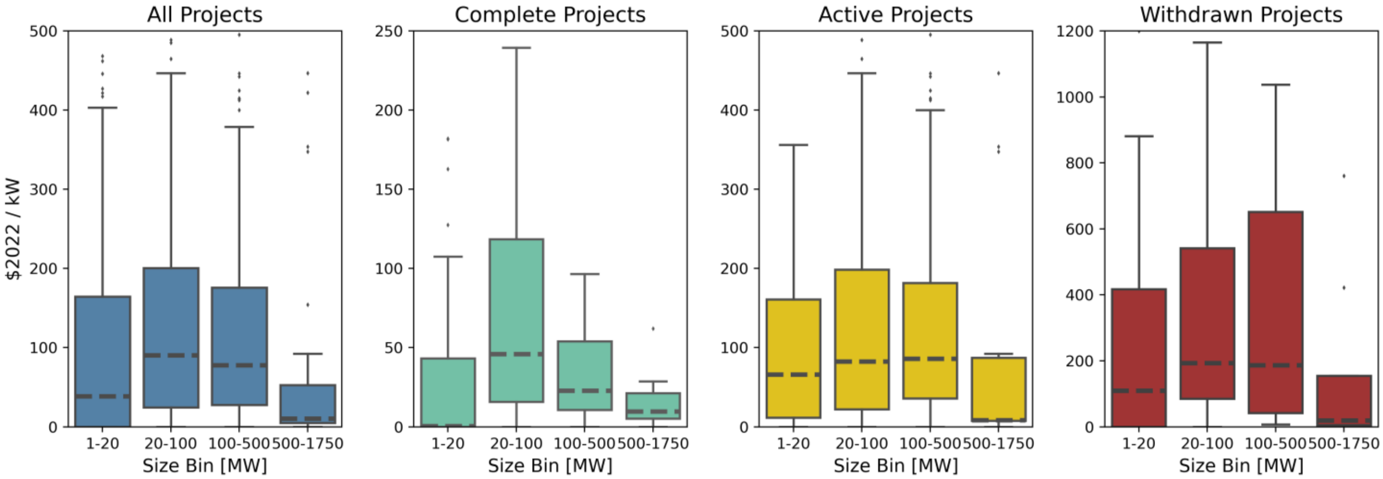

Figure 15 Total Interconnection Costs Request Status and Size Bin ***(y-axes differ by panel****, 2017-2022, not all outliers are shown)*

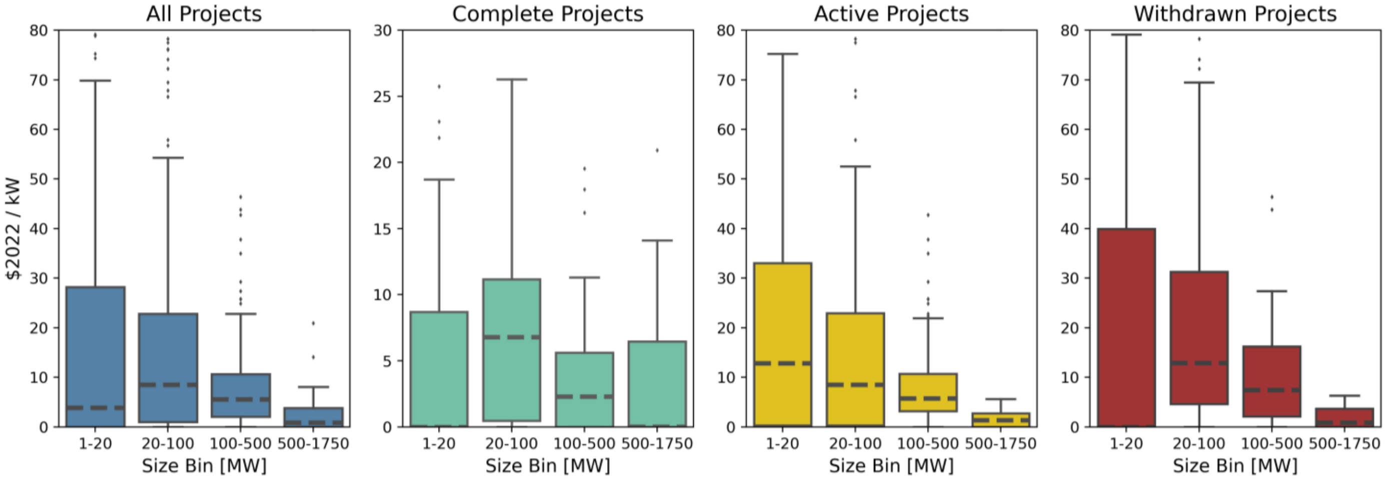

Figure 16 POI Interconnection Costs Request Status and Size Bin ***(y-axes differ by panel****, 2017-2022, not all outliers are shown)*

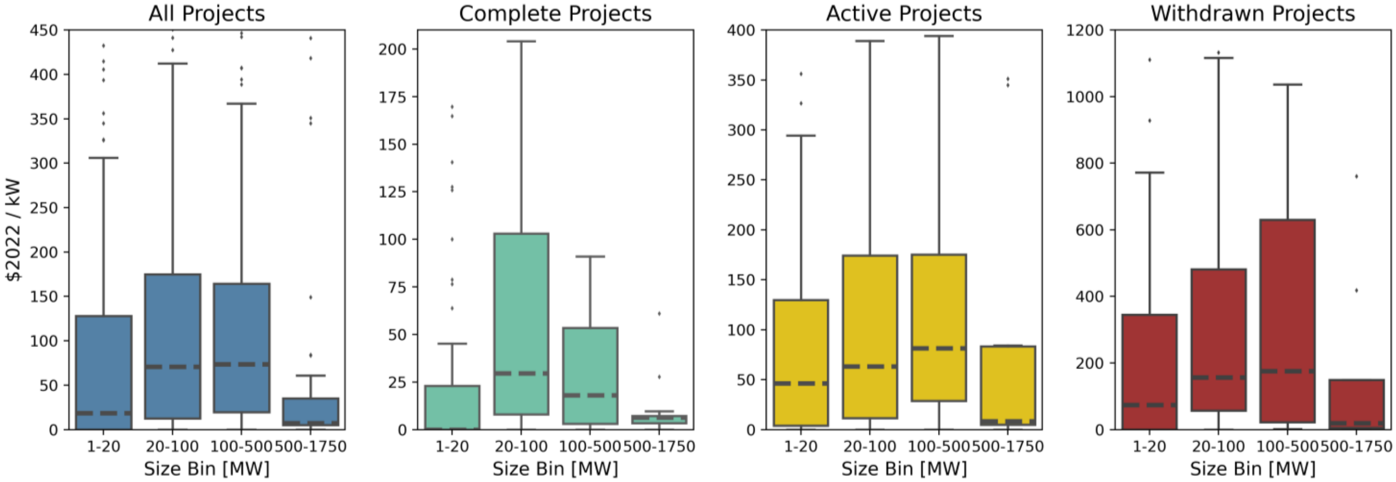

Figure 17 Network Interconnection Costs Request Status and Size Bin ***(y-axes differ by panel****, 2017-2022, not all outliers are shown)*

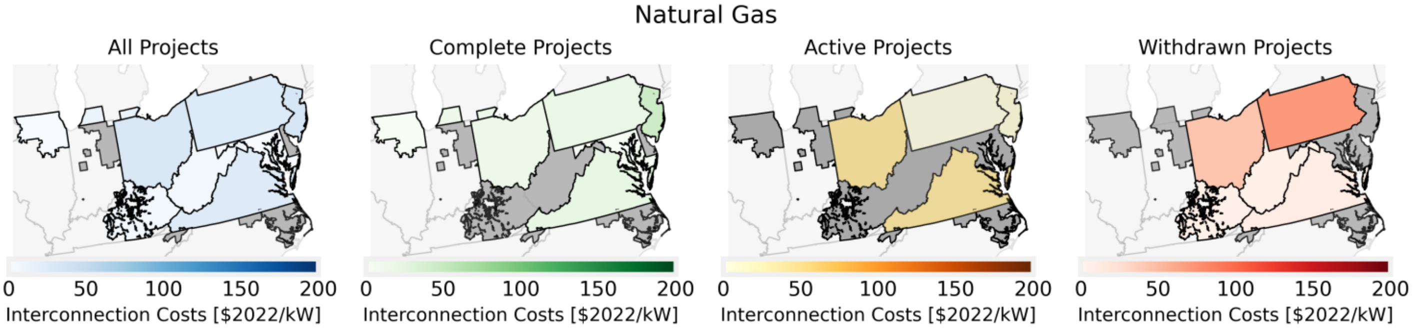

Figure 18 Interconnection Costs by State and Request Status: Natural Gas *(means, 2017-2022, grey areas indicate no data)*

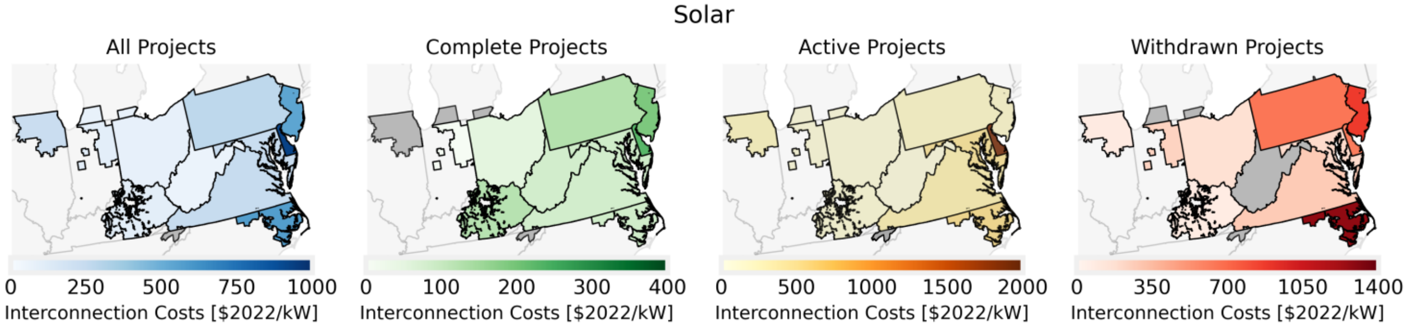

Figure 19 Interconnection Costs by State and Request Status: Solar *(means, 2017-2022, grey areas indicate no data)*

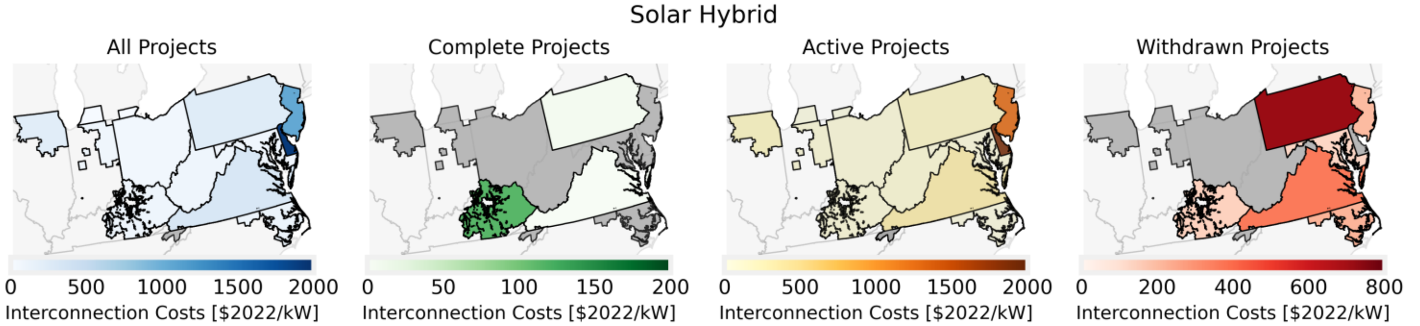

Figure 20 Interconnection Costs by State and Request Status: Solar Hybrid *(means, 2017-2022, grey areas indicate no data)*

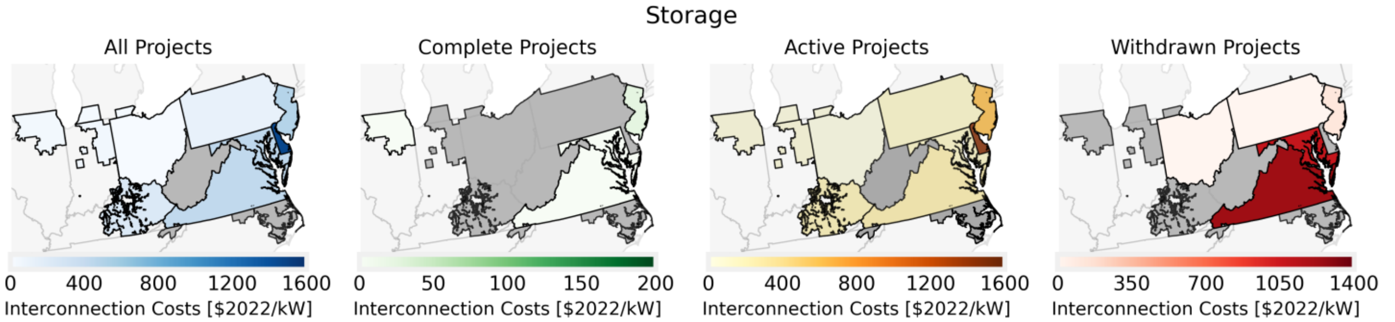

Figure 21 Interconnection Costs by State and Request Status: Storage *(means, 2017-2022, grey areas indicate no data)*

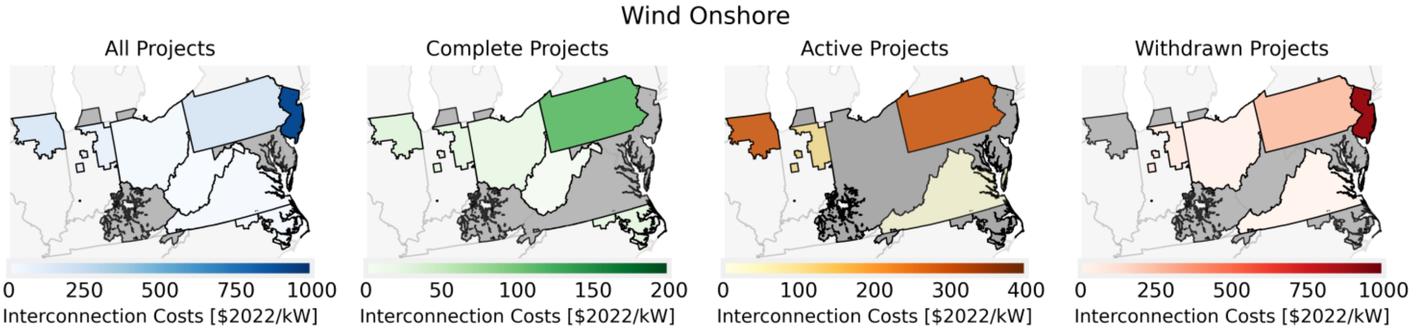

Figure 22 Interconnection Costs by State and Request Status: Wind Onshore *(means, 2017-2022, grey areas indicate no data)*

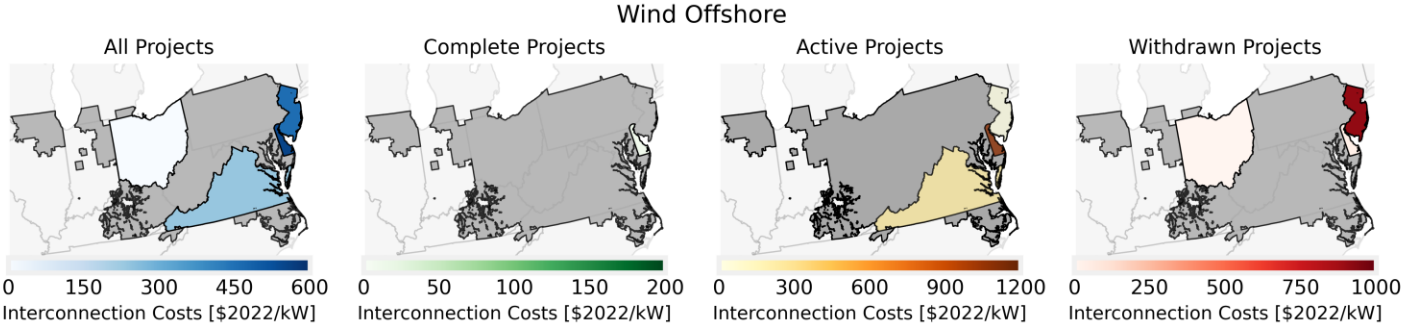

Figure 23 Interconnection Costs by State and Request Status: Wind Offshore *(means, 2017-2022, grey areas indicate no data)*