Title
Generator Interconnection Costs to the Transmission System in non-ISO Balancing Authorities

Authors
Seel, Joachim
Manderlink, Nick
Kemp, Julie Mulvaney
et al.

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Generator Interconnection Costs to the Transmission System in non-ISO Balancing Authorities

Joachim Seel, Nick Manderlink, Julie Mulvaney Kemp
Joe Rand, Will Gorman, Ryan Wiser (Lawrence Berkeley National Laboratory)
Will Cotton and Kevin Porter (Exeter Associates)

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https://emp.lbl.gov/interconnection_costs

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What are interconnection costs and why do they matter?

Regional grid operators require projects seeking to connect to the grid to undergo a series of studies before they can be built which establish grid system upgrade needs. Projects only acquire reliable interconnection cost estimates through these studies – itself a costly process with rising milestone payments. High interconnection costs impact project economics and often lead to withdrawal of the interconnection request, thereby introducing uncertainty into a queue process whose effective operation is needed to meet current expectations for higher levels of load growth.

The cost sample analyzed here represents 55% of all recent generators and storage requesting interconnection in 5 BAs (Pacificorp, BPA, Duke Progress/Carolinas/Florida) from 2020 to 2024. Visit https://emp.lbl.gov/interconnection_costs to access LBNL's interconnection cost research and the underlying dataset used for this analysis.

Glossary

- **Interconnection Request Status**
  - **Operational + Complete:**
    - Projects that completed the interconnection studies, and potentially interconnection agreement phase. Includes plants that are now in service.
  - **Active:**
    - Projects that were actively working through the interconnection study process.
  - **Withdrawn:**
    - Interconnection requests that have been permanently withdrawn (cancelled) from the queue.
  - **Suspended + Unknown:**
    - Interconnection requests with lacking meta data or projects that have been suspended with unclear final request status.

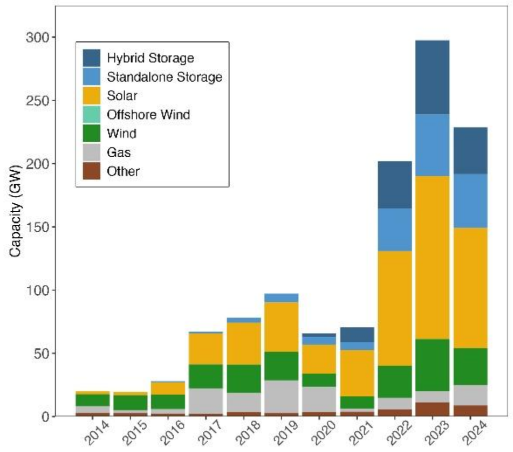
- **Interconnection Cost Components**
  - **Point of Interconnection (POI)** or Attachment Facilities Costs:
    - Interconnection station and transmission line extensions
    - Often excludes other infrastructure (step-up transformer, spur lines…)
  - **Network Upgrade** Costs:
    - Broader transmission network upgrades triggered by reliability or stability violations caused by a new generator.
    - May require modest upgrades (breakers) or reconstruction of several high-voltage transmission lines.
    - Costs may be shared by multiple generators that contribute to the upgrade.

Reported generator interconnection costs are drawn from a sequence of interconnection studies (feasibility, system impact, and facilities studies) and should be interpreted as preliminary estimates rather than final, settled amounts. Generator Interconnection Agreements (GIAs) typically provide more authoritative cost estimates, but we could not incorporate them in this study due to data limitations. Projects that withdraw their interconnection requests generally are not required to pay the full quoted interconnection costs, although milestone or study fees already paid are typically nonrefundable. For projects listed as completed or operational, realized interconnection costs may exceed the amounts reported here due to cost escalation and scope changes at or after GIA execution.

High-Level Findings

Interconnection cost data transparency is insufficient and has contributed to ballooning interconnection queues

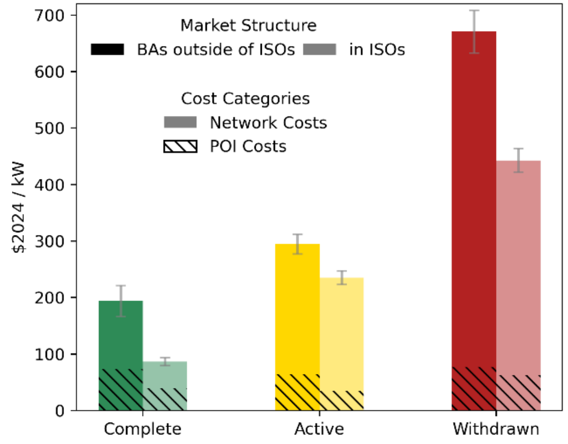
- Interest in developing new resources is high: active queue capacity across 5 BAs (PAC, BPA, Duke Progress /Carolinas / Florida) tripled from 2020 to 2024.
- Most requests withdraw after receiving cost estimates, and only 15% of pre-2019 projects were online by end of 2024.



Active Interconnection queues in 5 BAs

Recent interconnection costs in our non-ISO Balancing Authorities (BAs) sample are higher than in ISOs

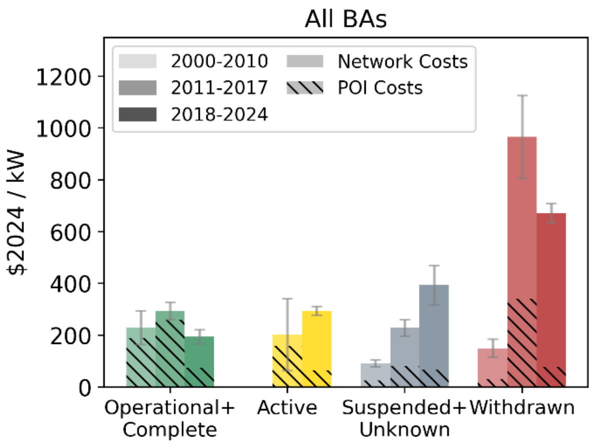
- Costs are higher across all recent projects and for each request status (double for complete projects).
- Network costs explain most cost differences.
- Developers in non-ISO BAs seem to have higher willingness to pay.



Interconnection costs in 5 BAs and 5 ISOs

Interconnection costs have increased since the early 2000s

- Costs for "complete" projects (2018-2024 : $194/kW) have remained stable in some regions and grown in others. Active ($294/kW) and withdrawn ($671/kW) projects have greater costs.
- Network upgrade costs are the primary driver of recent cost increases, especially among withdrawing projects.



Interconnection costs in 5 BAs over time

Interconnection costs vary across multiple categories

- Recent larger generators have lower average proportional costs ($763/kW for small vs $243/kW for very large projects).
- Recent natural gas projects ($150/kW / no recent completions) have lower average costs than solar (all: $509/kW / complete: $216/kW), land-based wind ($504/kW / $103/kW), and storage projects ($437/kW / $151/kW).
- Firmer interconnection service (NRIS: $467/kW / $133/kW) comes with greater network upgrade costs (ERIS: $353/kW / $50/kW).
- High network upgrade costs are often clustered geographically.

DOE’s Interconnection Innovation e-Xchange (i2X)

Mission: To enable **simple**, **fast**, and **affordable** interconnection while enhancing the **reliability** and **security** of our **electric grids**

Stakeholder Engagement

- Nation-wide *engagement platform* and collaborative exchanges
- Generate innovative solutions from discussion with utilities, grid operators, state/local governments, developers, non-profits

Data & Analytics

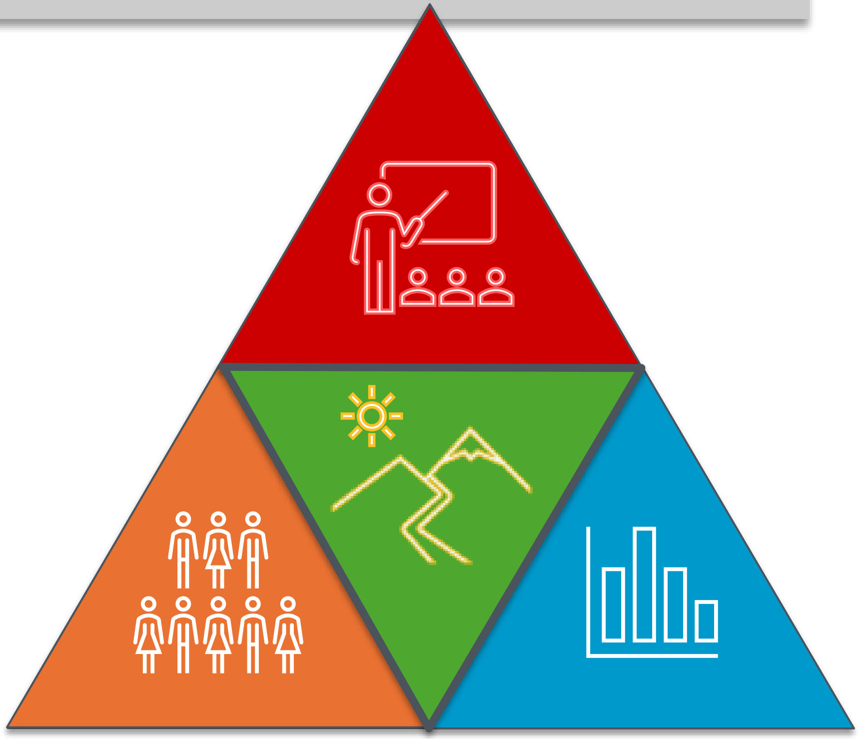
- Collect and analyze interconnection data to *inform solutions development*
- Increase transparency of interconnection process

Strategic Roadmap

- Create roadmap to inform interconnection process improvements
- Identify both *near- and long-term opportunities* and solutions

Research and Innovation

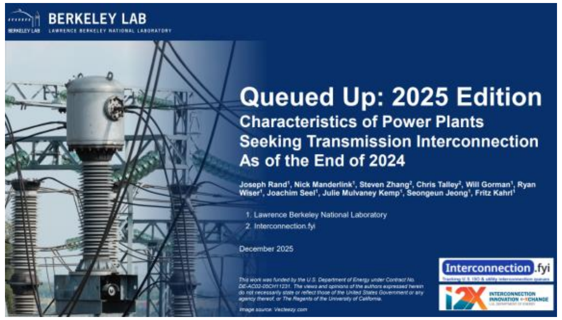
- Leverage DOE laboratory expertise to *test and pilot software*



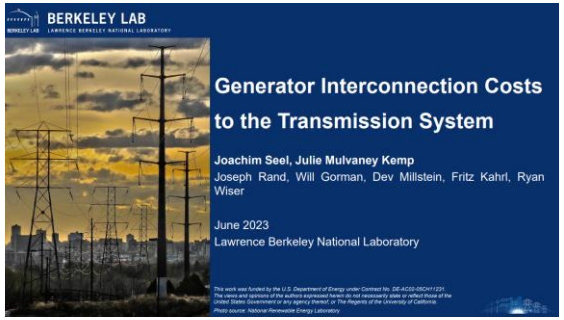
INTERCONNECTION INNOVATION e-XCHANGE
U.S. DEPARTMENT OF ENERGY

A DOE initiative supported by the Office of Critical Minerals and Energy Innovation

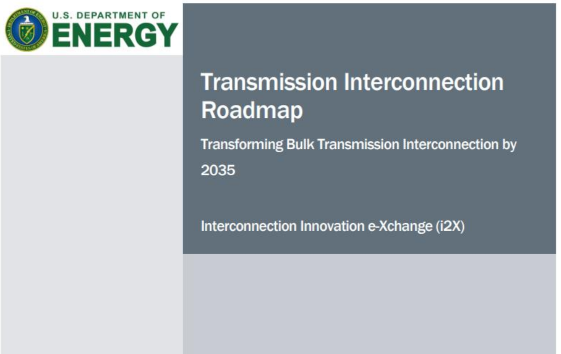
Background on Berkeley Lab’s transmission interconnection research



- Collecting and analyzing interconnection queue application trends and timelines
  - Annual Queued Up report assessing the 2.3 Terrawatts (end of 2024) of generation and storage capacity seeking connection to the bulk power grid in the United States. Investigates interconnection queue dynamics, completion and withdrawal rates, and process duration.



- Collecting and analyzing the cost of interconnecting new resources
  - Analysis of interconnection cost data for projects in MISO, PJM, SPP, ISO-NE, NYISO, and CAISO for studies performed between 2010 and 2023. ISO-specific technical briefs and cleaned interconnection cost data files are available for download.



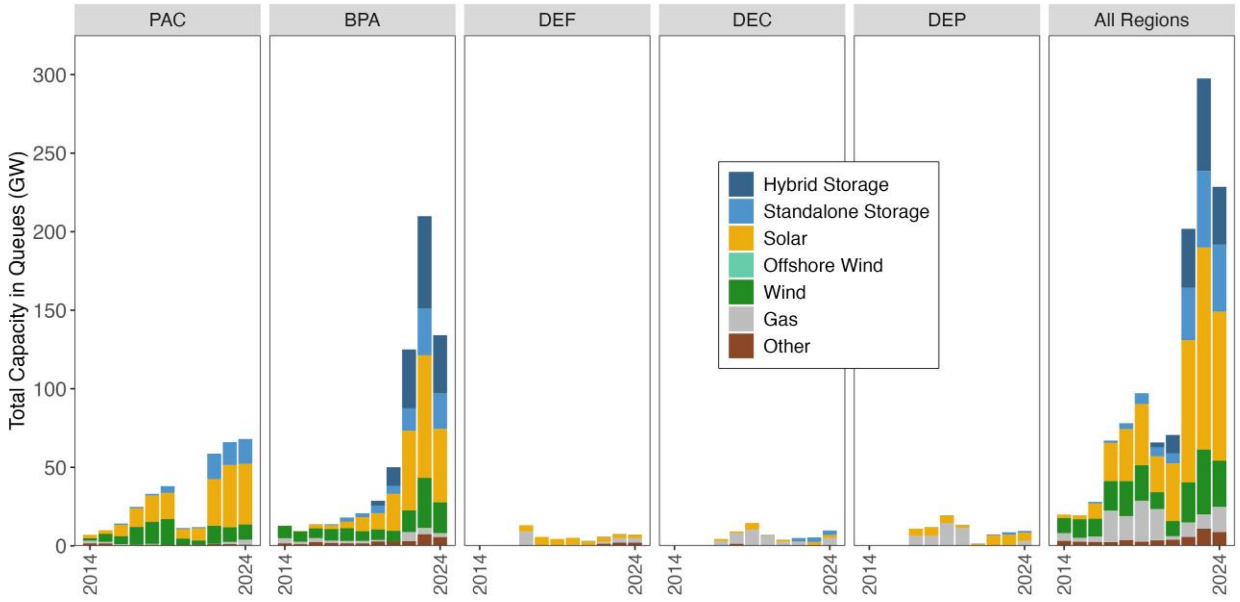
- Researching opportunities for interconnection queue reforms
  - Developed Transmission Interconnection Roadmap by engaging broad stakeholder community via DOE’s i2X initiative through multiple webinars and workshops to identify 35 solutions enabling an improved interconnection process of new energy resources while enhancing reliability, resiliency, and security of our electric grid.

Generator Interconnection Costs and Impacts on Queue Management

Interconnection queues have grown rapidly in BPA and PAC but had a consistent size in the Duke BAs

- This analysis investigates generator interconnection to the bulk power transmission system in five Balancing Areas (BAs) outside of the major ISO/RTOs: The Bonneville Power Authority (BPA), PacifCorp East and West (PAC), Duke Energy Carolinas (DEC), Duke Energy Progress (DEP), and Duke Energy Florida (DEF). To facilitate interpretation of our findings we combine the three Duke BAs into one category in most graphs but show detailed results in the Appendix.

- At year-end 2024, the five BAs had 229 gigawatts (GW) of generation and storage capacity actively seeking grid interconnection. Capacity in these queues comes from solar (95 GW), standalone storage (43 GW), wind (29 GW), and natural gas (16 GW). The queues also contains data for projects no longer seeking interconnection, both those that are in service (25 GW) and those whose applications have been withdrawn (450 GW) (Rand et al. 2025).



- Interconnection queues have ballooned in recent years in some BAs, especially in BPA (2024's active queue increasing 875% compared to year-end 2017) and PAC (174%). The capacity associated with interconnection requests across the five BAs is roughly 4x as large as their combined peak load in recent years (~65 GW).

Interconnection cost responsibilities in non-ISO BAs

- Standard rules governing the interconnection of new generators were introduced by FERC in Order 2003 in the pro-forma open access transmission tariffs (in some respects revised under Order 2023).

- Participant Funding: In the service territory of most ISOs/RTOs (ISO-NE, NYISO, PJM, SPP, MISO), transmission providers usually charge *interconnection customers* (ICs) for any upgrades required "but for" the new generator. The IC receives financial transmission rights for any new transmission capacity created, although implementation and exact cost allocation can vary by ISO.

- Crediting Policy: In CAISO and non-ISO BAs, the IC also pays for upgrades required by the new generator up front. However, up-front expenses that provide system-wide benefits (e.g., network upgrade costs) are often refunded by the transmission provider to the IC over time and with interest, up to 20 years. Details of the crediting policies can vary by BA.
  - The IC remains responsible for any local costs at the point of interconnection (Attachment Facilities).
  - The IC can only receive credits if the generator achieves commercial operation, and all network upgrades have been completed and paid for by the new generator.

Interconnection costs impact overall queue management and infrastructure buildout at a time of high expected load growth

- Interconnection customers often do not have a clear sense of expected interconnection costs prior to submitting an interconnection request to the queue and use interconnection studies as means of cost discovery – itself a costly process with rising milestone payments.
  - Transparency around available transmission capacity by location can still be much improved, especially outside of the main ISO/RTOs.
  - FERC 2023 requires transmission capacity availability maps based on recent cluster study results, but those have not been implemented in most BAs as of early 2025.

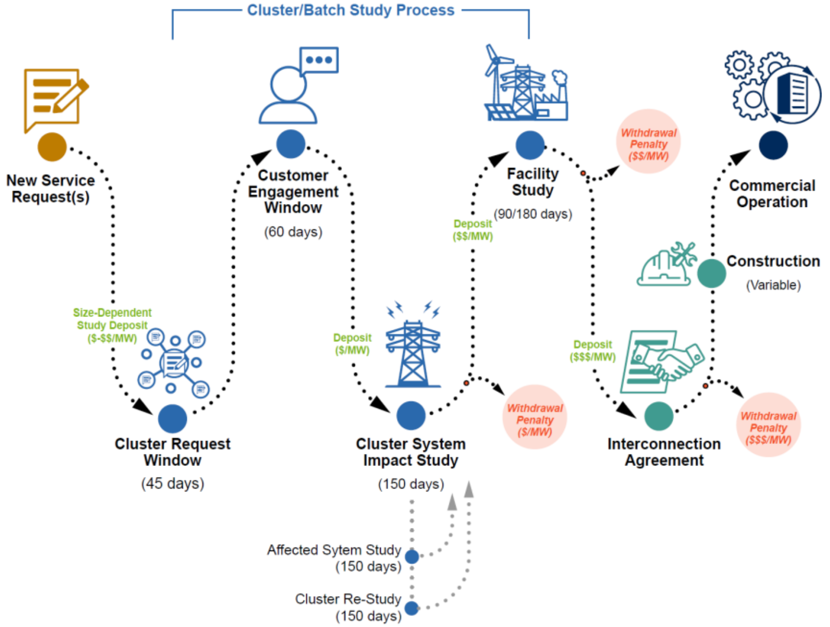
- High interconnection costs impact project economics and often lead to request withdrawal, thereby introducing uncertainty into the queue management process and impeding rapid interconnection of new generation resources.
  - Historically, most projects withdraw in our 5 BAs: only 15% of projects requesting interconnection from 2000 to 2019 achieved commercial operation by year-end 2024.
  - While the IC can be ultimately refunded for interconnection costs in non-ISO BAs, they still face financing costs up front. For example, high interconnection costs of $500/kW represent charges of $50 million for a 100MW generator. Although ICs can receive interest on their network upgrades, it may not fully cover their capital carrying costs.

- Multiple future reform options of interconnection cost responsibilities have been discussed:
  - Clearer alignment between generator interconnection assessments and longer-term regional transmission planning → ICs would not have to pay for broadly beneficial upgrades.
  - Distinction between Highway and Byway funding (IC pays more for network upgrades up to substation but less for high voltage upgrades).
  - Use distribution factors to get a more accurate estimate of ICs transmission line utilization and only pay for their proportional usage.
  - Greater use of a minimum interconnection standard at lower costs (e.g., ERIS with curtailment risks).
  - Standardized fee-based approach of generators paying into a pool that funds base transmission upgrades (e.g. SPP’s consolidated planning process proposals).

FERC Order 2023 is a fundamental reform of the generator interconnection process that will impact practices in all BAs

- FERC Order 2023 required fundamental changes to the interconnection process (cluster studies, first-ready-first served approach, higher deposits, readiness criteria and withdrawal penalties, more stringent timeline and reporting requirements for transmission providers, better geographic information about available transmission capacities, and consideration of alternative transmission technologies).
- Non-ISO BAs must comply with FERC Order 2023 and had to file tariff revisions by May 2024, either by *verbatim adoption* of FERC's pro-forma LGIP/LGIA or by proving *consistent or superior alternatives*. BPA as a federal agency is not strictly bound by FERC Order 2023 but recognized the need to align with best practices. In response to rapidly rising interconnection queues, PAC and BPA already implemented major queue reforms prior to FERC Order 2023. In DEP/DEC some reforms were initiated by the North Carolina Utility Commission.
- Most of the interconnection cost data collected here stem from interconnection studies performed prior to the recent reforms and provide thus a baseline against which future improvements can be measured. Not all Order 2023 actions have been implemented yet across the BAs.

	PAC	BPA	DEP/DEC	DEF
Last major reform of interconnection process	2020 , 2023	2024	2020	2019
FERC Order 2023 Implementation	LGIP amendments	n/a	FERC 2023 pro-forma SGIP, LGIP amendments	FERC 2023 pro-forma LGIP
Implementation of Cluster studies + First ready-first served	2021	2024	2021	2024



Methods and Data Sample Descriptions

Interconnection cost data: Methods used for sample creation

- Collected robust sample of 2100+ project-level interconnection cost estimates (collected all in 2024).

Region	Time to collect (per project / total)	Project cost sample
BPA	30-45 min / 150h	296 estimates (serial: 198 studies / no cluster results up to July 2024).
PAC	15-30min / 290h	1117 estimates from 6 queues (serial: 502 studies / cluster estimates: 418 up to Cluster 3 of 2024/05)
DEC	35-65min / 150h	187 estimates (serial: 90 studies / cluster estimates: 65 up to 2023 Cluster Phase 1 of 2024/04)
DEP	10-30min / 65h	300 estimates (serial: 164 studies / cluster estimates:154 up to 2023 Cluster Phase 1 of 2024/04)
DEF	30-45min / 135h	204 estimates (serial: 219 studies / no cluster results up to 2024/03)

- Costs are quoted interconnection costs in interconnection studies. While initially paid by the developer, some cost components (network costs) are often reimbursed over time by the transmission owner. Costs thus represent total system expenses and not net present value costs to the developer.

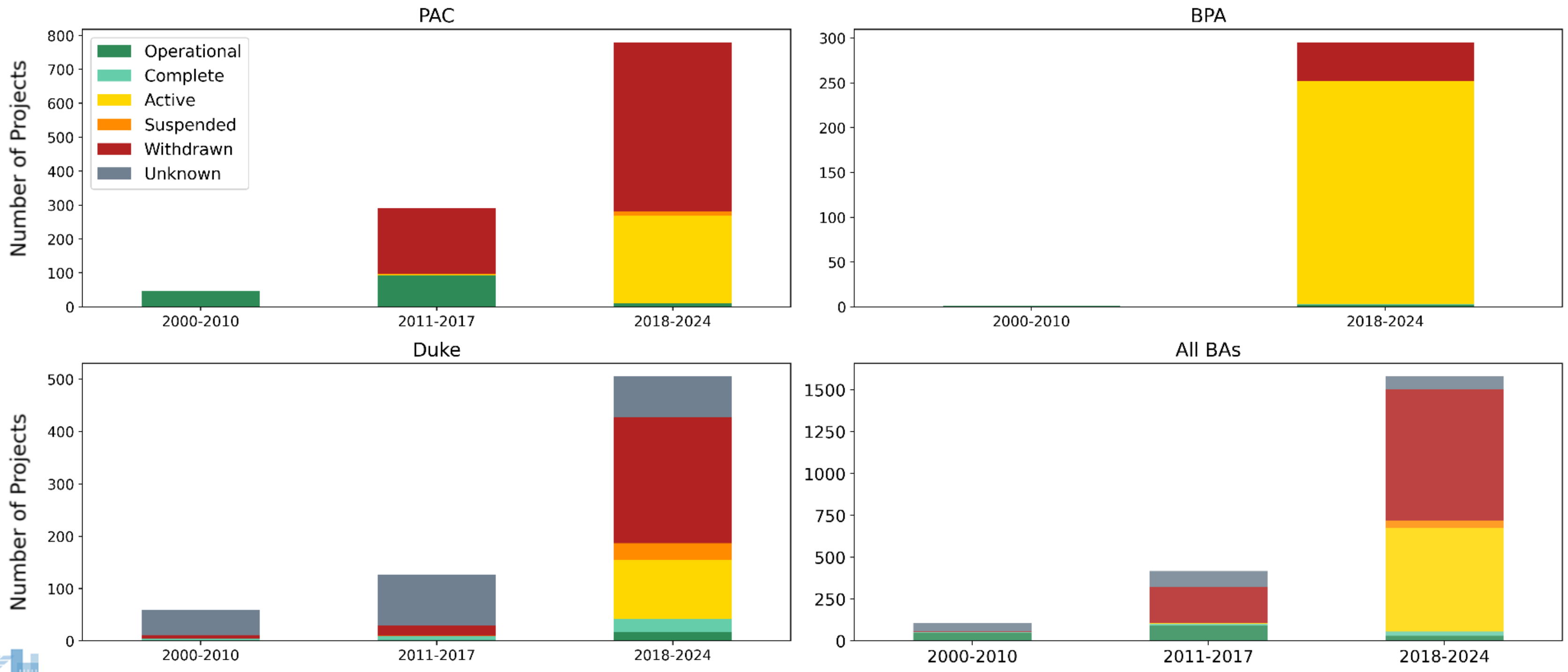
- Cost data are only a subsample of all projects in the interconnection queues:
  - Interconnection studies are often not yet available for most recent queue entrants
  - BAs often remove cost publications for older projects
  - Some projects may withdraw before cost estimates are released
  - Focus on new and unique generators (not uprates of existing projects)

- Temporal coverage: 2000-2024
  - Costs indexed by interconnection study year (not queue entry), real \$2024-terms/kW_{AC} (GDP deflator conversion)
  - Using most recent cost estimate available at time of data collection (mostly spring-summer 2024)

Sample creation required manual cost extraction from study pdfs averaging 20 minutes per project, equivalent to about 700 hours for the entire sample. The lack of easily accessible machine-readable 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 .

PAC data dominates the interconnection cost sample

- PAC has the most sample data (1,117 projects) and thus an outsized impact on aggregate statistics across all BAs. Many DEP/DEC projects have unknown request status as we are unable to match posted studies with general interconnection queue lists (inconsistent queue IDs).
- Most projects with cost estimates ultimately withdraw from the queue (1,001), followed by active (623), unknown (223), operational (172), suspended (48), and complete (37) requests.



Note that the y-axis scaling varies between subplots.

Interconnection Request Status Definitions

Operational + Complete: Projects that completed the interconnection studies, and potentially interconnection agreement phase. Includes plants that are now in service.

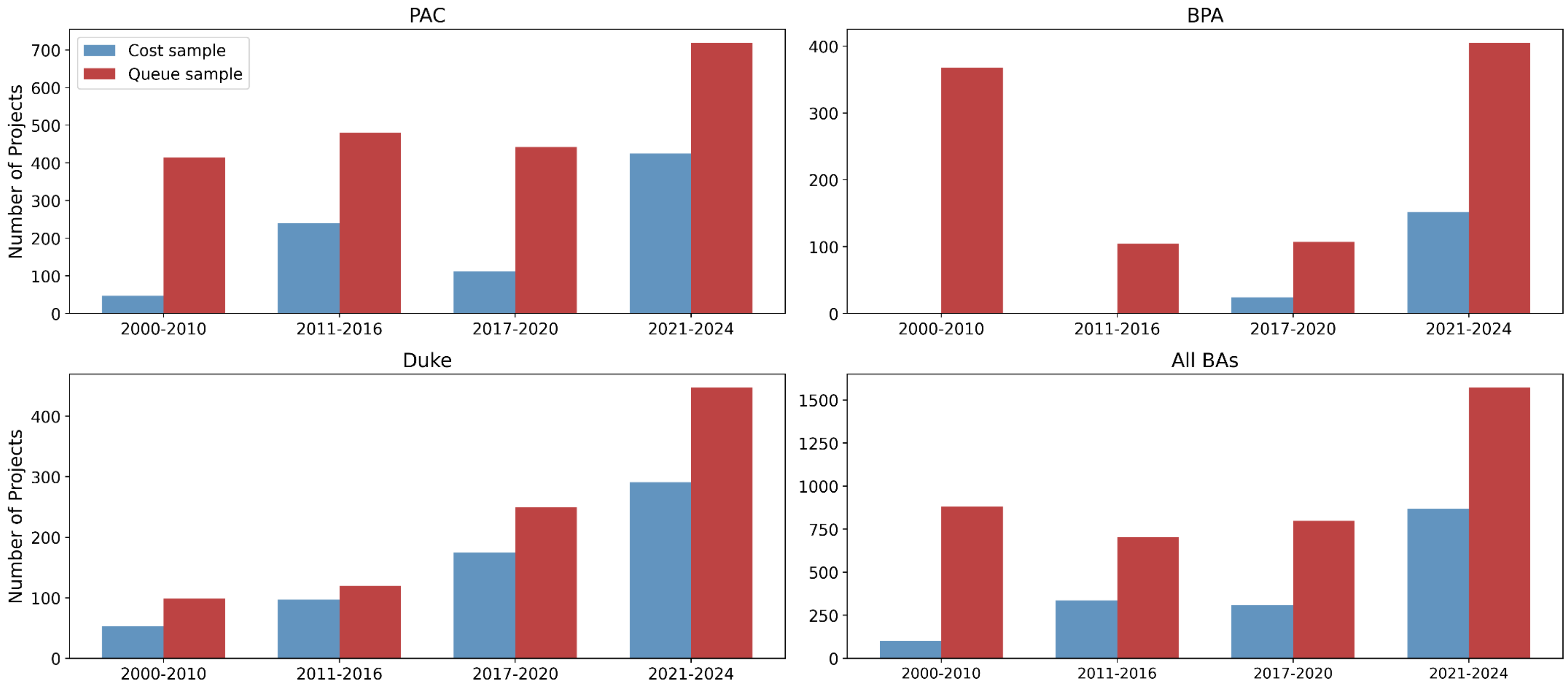
Active: Projects that were actively working through the interconnection study process.

Withdrawn: Interconnection requests that have been permanently withdrawn (cancelled) from the queue.

Suspended + Unknown: Interconnection requests with lacking meta data or projects that have been suspended with unclear final request status.

Interconnection cost sample is robust for recent queue entries

- Aggregate interconnection cost sample has 41% coverage relative to all interconnection requests since 2000, ranging from 18% in BPA to 76% in DEC
- Data for recent cost estimates (2021-2024: 55%) is more robust than in earlier years and is thus the focus of our analysis.



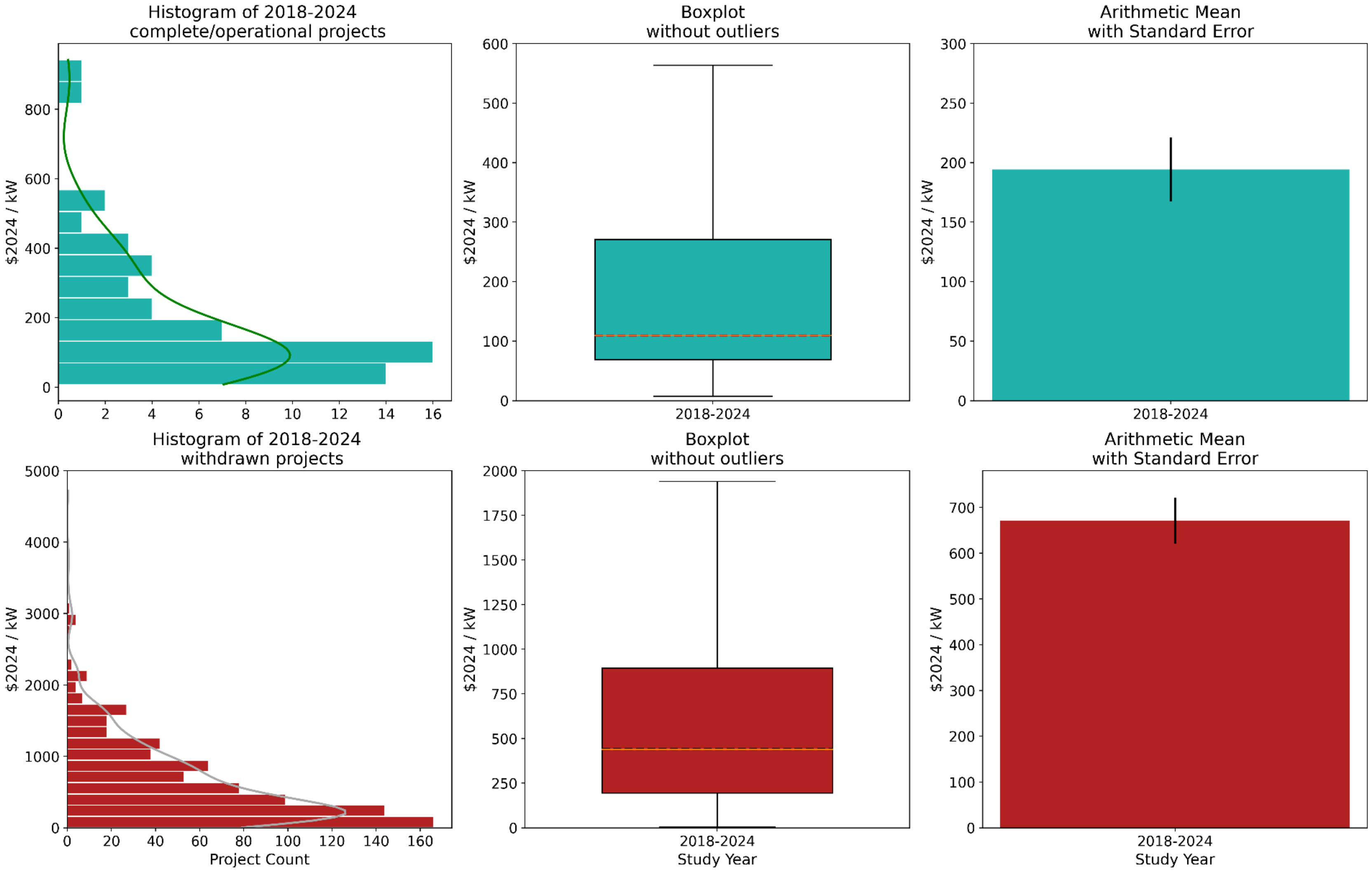
Graph compares number of projects **entering the interconnection queue** over a given period with the **most recent interconnection cost study** performed in that period.

Studies are usually performed 1-3 years after a project enters the queue. Bars are thus not expected to line up perfectly and cost estimates are not available for most recent queue entries.

Note that the y-axis scaling varies between subplots.

Interconnection cost data is often skewed and does not have a normal distribution

- Many projects (especially those that complete the interconnection process) have low costs.
- Some projects with very high interconnection costs have outsized influence on sample mean.
- We rely on mean statistics as they allow for summation of partial data (e.g. POI and Network costs). Most trends presented here also hold when looking at typical (median) projects.

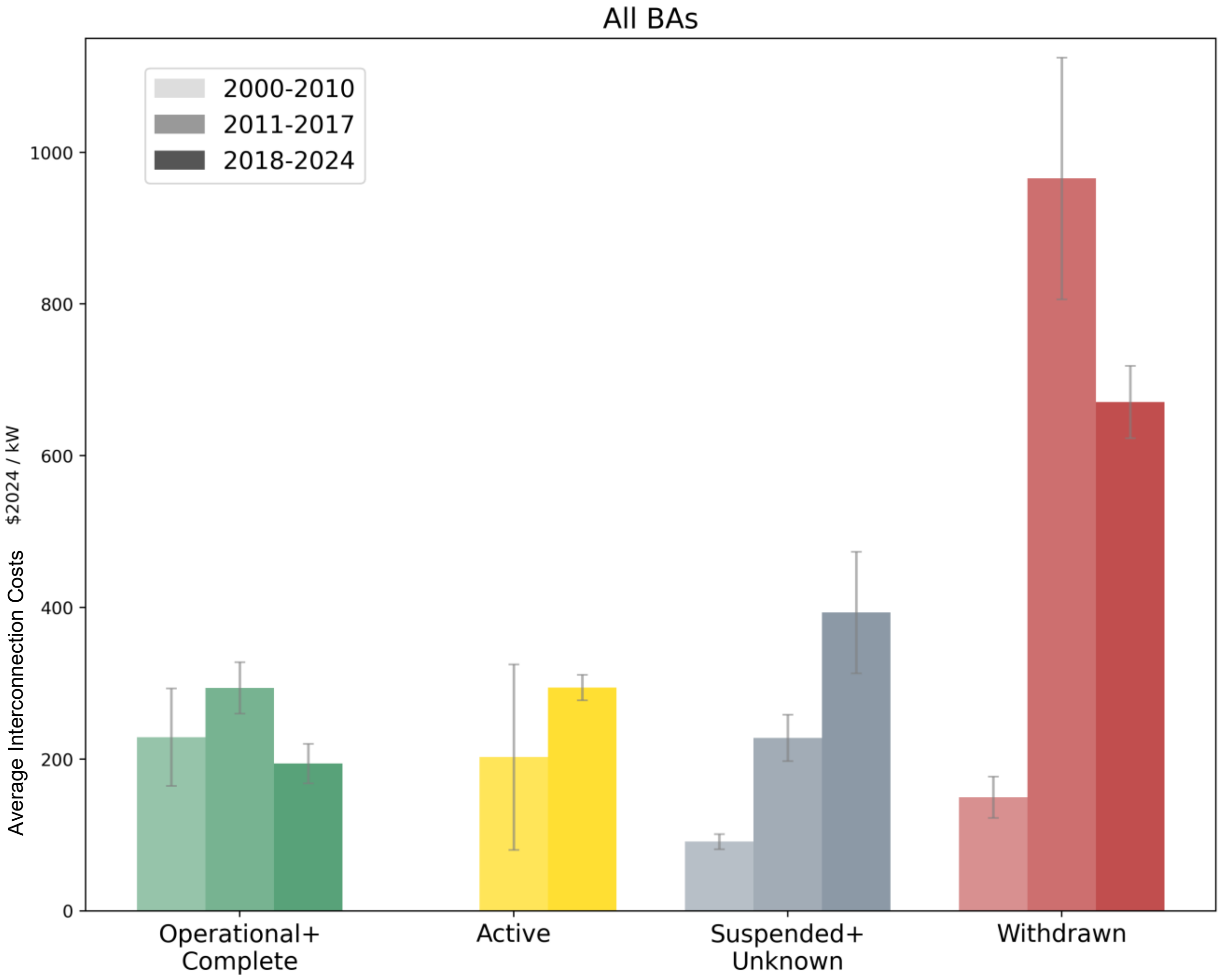


Data includes interconnection costs in the 5 BAs studied 2018-2024: PAC, BPA, DEC, DEP, DEF.

Main Findings

Interconnection costs have increased since the early 2000s and are higher for projects that ultimately withdraw

- Interconnection costs have increased across all regions since the early 2000s, rising from $162/kW to $485/kW (2018-2024). However, they remain below the peak of $620/kW (2011-2017).
- Among "complete" projects, costs have stabilized after a temporary rise in the early 2010s. In contrast, projects that are still in the queue, have an unknown status, or have withdrawn have seen interconnection costs increases over time.
- Recent (2018-2024) projects that complete all studies have the lowest interconnection costs ($194/kW), compared to active ($294/kW) and withdrawn ($671/kW) projects.

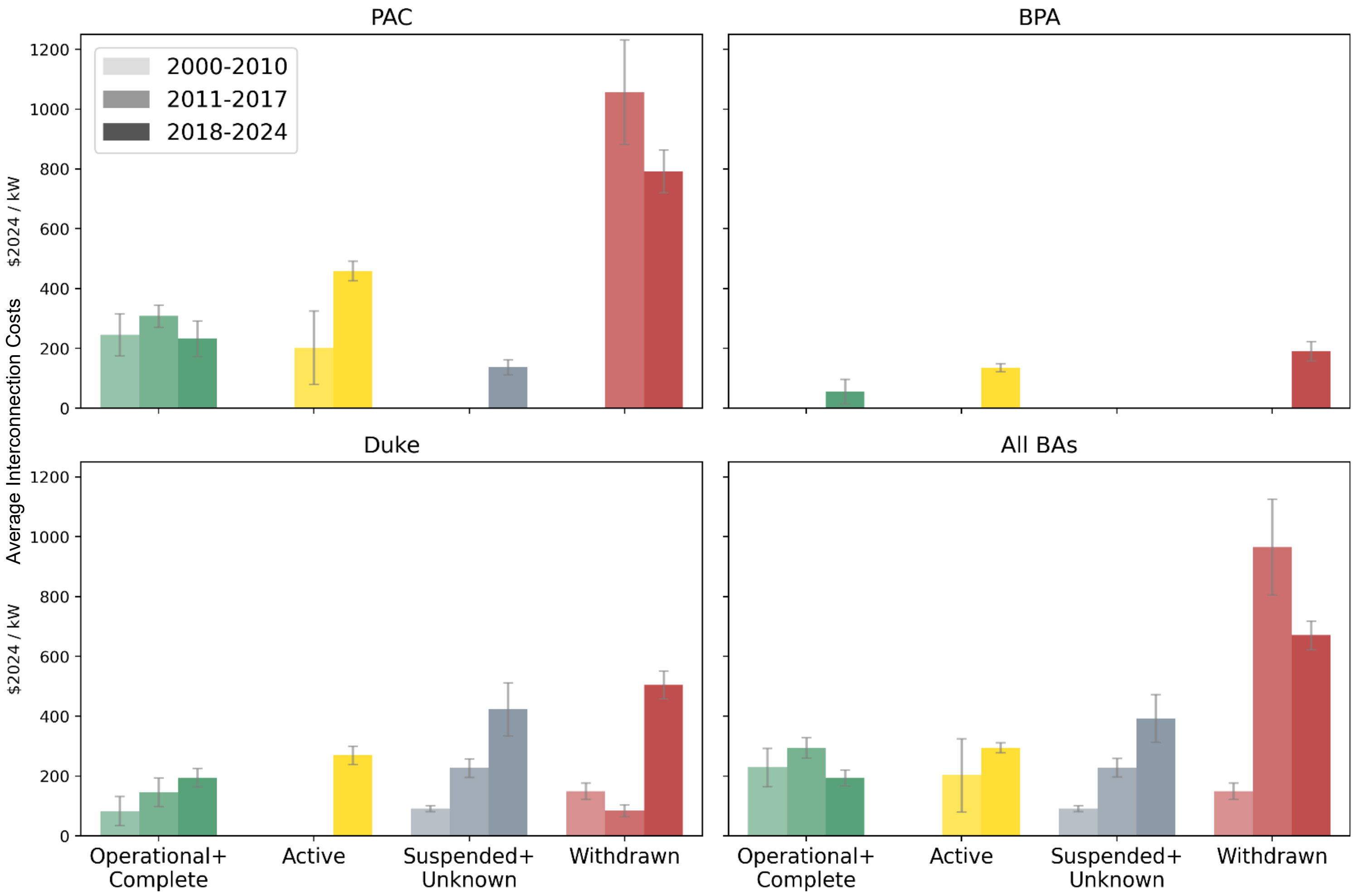


PacifiCorp has higher interconnection cost than Duke and BPA

- PAC statistics heavily influence the "All BA" statistics, as this region has the most cost observations. At the same time, PAC interconnection costs tend to be higher than in other regions.

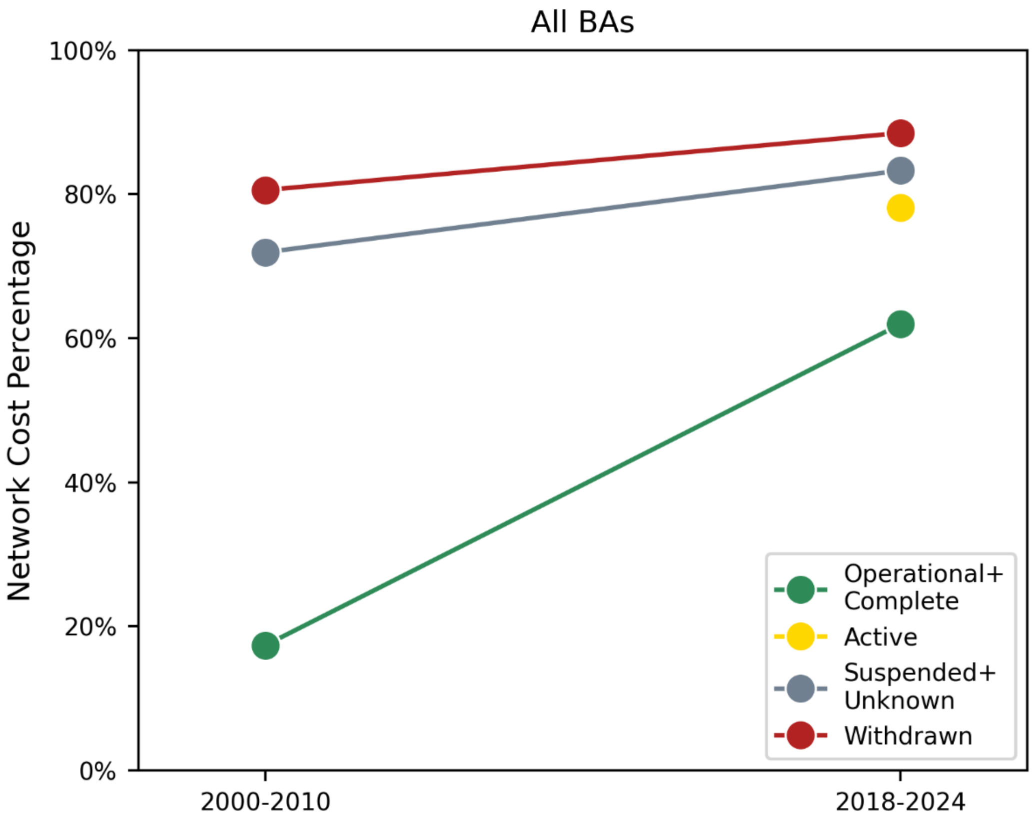
- While projects with completed studies have experienced cost stability in PAC, the Duke regions (DEC, DEP, DEF) have seen greater cost increases over time. BPA lacks sufficient historical interconnection data for a trend assessment.

- Recent average interconnection costs for complete projects are lowest in BPA ($56/kW) and highest in DEC ($497/kW).



Broader network upgrades drive recent interconnection cost increases

- The share of network upgrade costs varies by request status, playing a greater role among withdrawn projects than completed projects.
- Overall, network upgrade costs as a proportion of total interconnection costs have increased over time, rising from 35% in the 2000s to 85% in 2018-2024 (across all projects irrespective of request status).



Interconnection Cost Components

Point of Interconnection (POI) or Interconnection / Attachment Facilities Costs:

- Interconnection station and transmission line extensions
- Often excludes other infrastructure (step-up transformer, spur lines…)

Network Costs:

- Broader transmission network upgrades triggered by reliability or stability violations caused by a new generator.
- May require modest upgrades (breakers) or reconstruction of several high-voltage transmission lines.
- Costs may be shared by multiple generators that contribute to the upgrade.

Share of network upgrade costs vary by BA

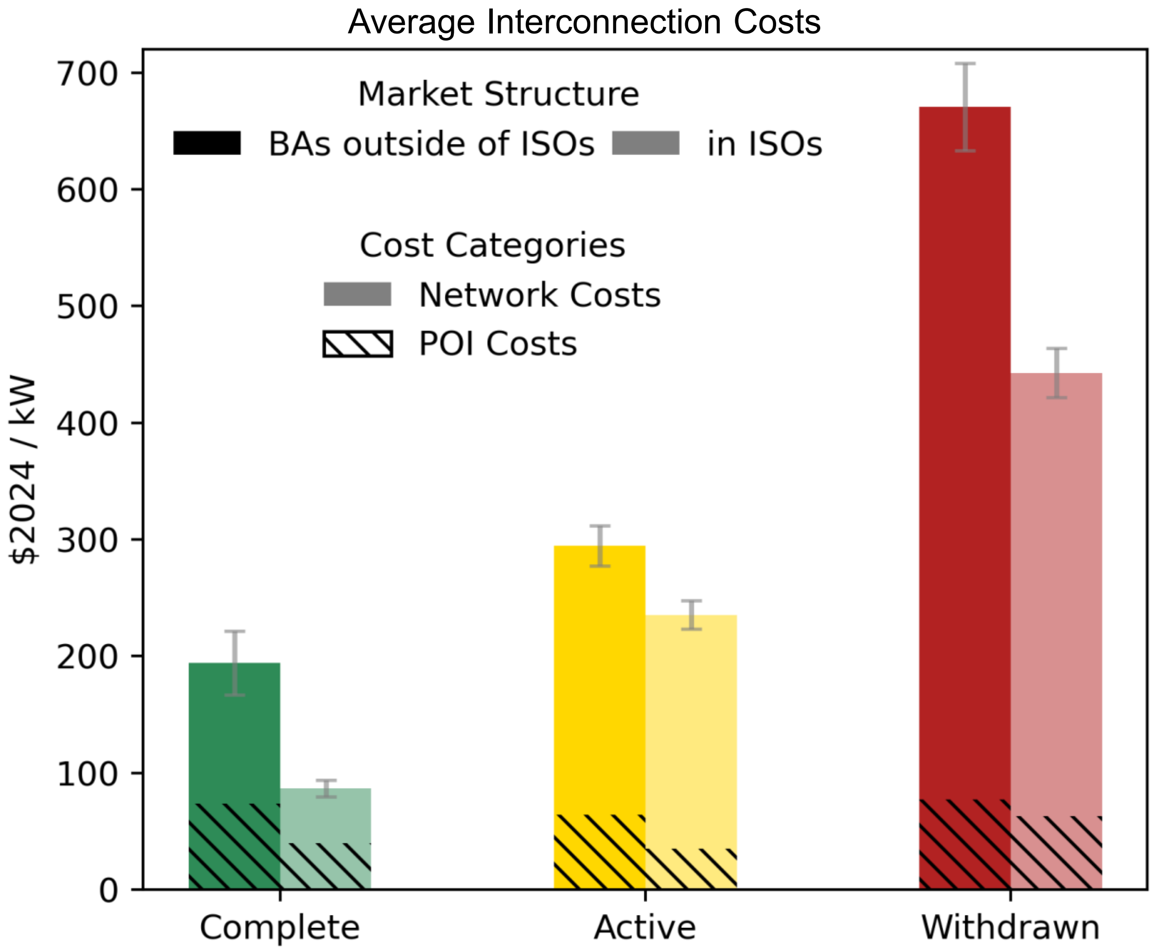
Interconnection cost categories are not consistently defined by each BA and require some judgement during data collection process.

- POI costs (hatched portion of the bar) account for a large share of total interconnection costs in BPA (67%) but remain low in DEC (13%) across all request statuses.

- In PAC complete projects have higher POI costs in $/kW terms compared to active, unknown or withdrawn projects.

Recent interconnection costs in our BA sample are higher than in ISOs

- Past Berkeley Lab research collected interconnection data from five ISOs (MISO, SPP, PJM, NYISO and ISO-NE). The ISO sample is dominated by regions with low population and transmission density (MISO and SPP) and has a similar fuel mix, making it roughly comparable to the non-ISO BAs.
- Costs in the non-ISO regions are higher across all recent projects and for each request status (complete projects costing more than twice as much).
  - PAC and Duke Carolinas/Florida have the greatest costs, while BPA often has lower costs compared to other ISOs.
- Network upgrade costs explain most of the differences, although POI costs are also greater in the non-ISO BAs.
- Our findings point to structural differences in interconnection costs as even costs for withdrawn projects are higher in non-ISO BAs. Developers in non-ISO BAs also seem to have a higher willingness to pay to connect their projects to the transmission system - potentially due to different approaches for the payment of and reimbursement of network upgrade costs.



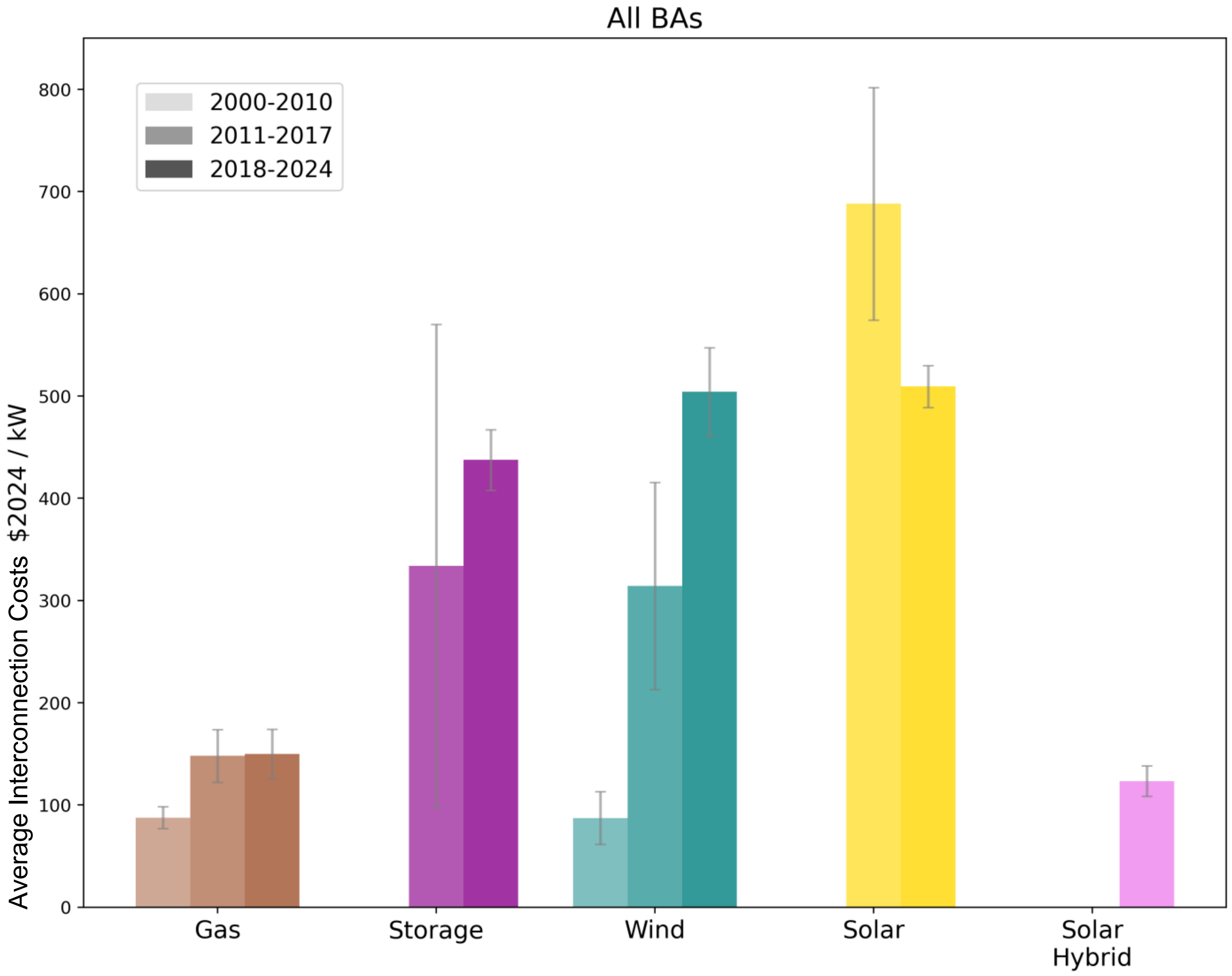
ISOs *interconnection cost data are from MISO (n=1280), SPP (815), PJM (783), NYISO (109), and ISO-NE (58) from studies conducted between 2018 and 2023.* ***Non-ISO*** *data are from PAC (766), BPA (295), and Duke Energy (395) from studies conducted between 2018 and 2024).*

Interconnection costs have grown for most fuel types over time

- The averages in the graph on the right include projects that ultimately withdraw their interconnection applications, leading to higher overall costs compared to "complete" projects (see Appendix).

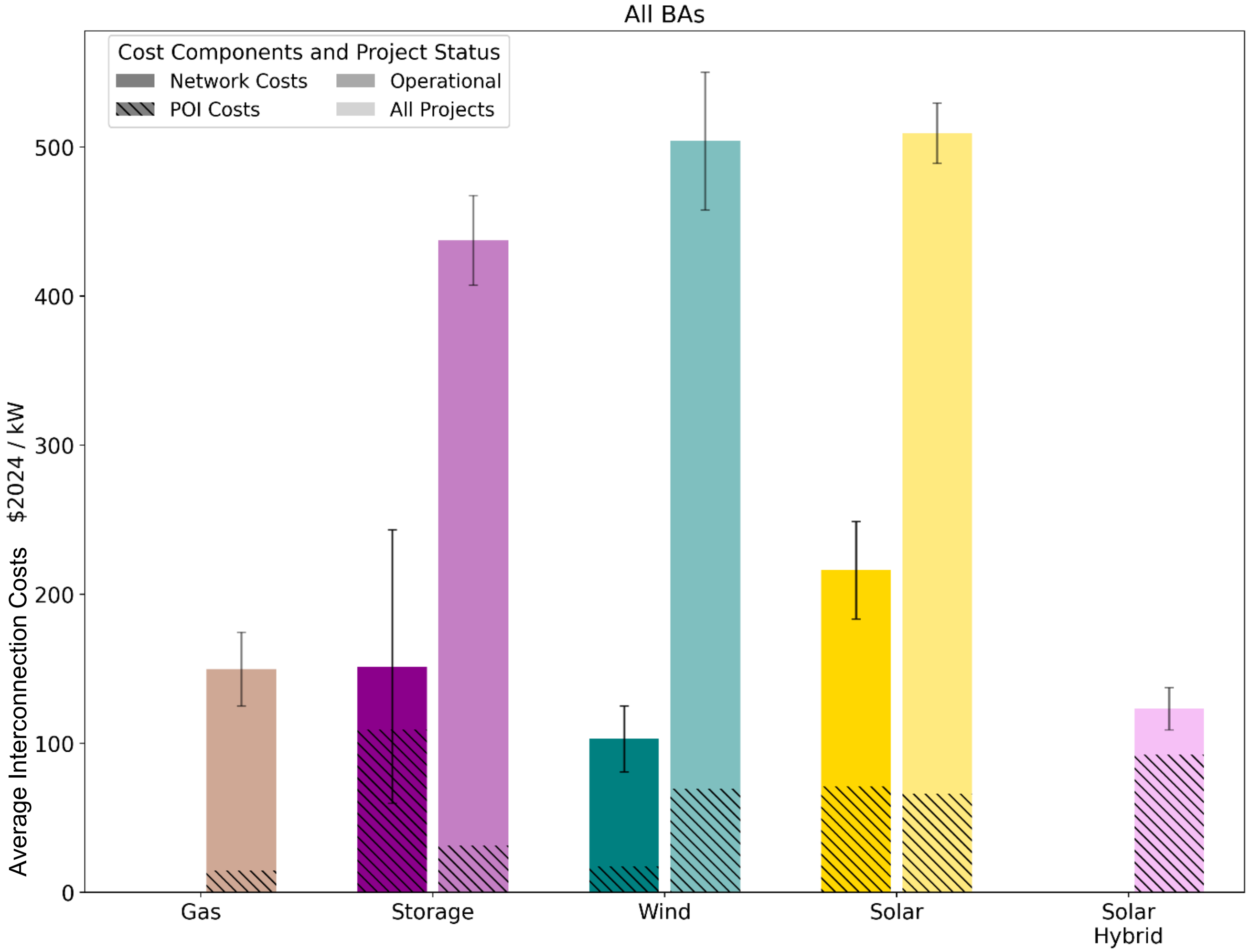
- Interconnection costs have risen over time for natural gas, storage, and especially land-based wind projects.

- Aggregate solar interconnection costs across all BAs have fallen, but this trend is driven by PacifiCorp data. In the Duke BAs solar interconnection costs have doubled since the early 2010s (see Appendix).



Solar, wind, and storage projects that complete all studies have interconnection costs more like natural gas projects

- Among all recent interconnection requests (right pale bar) solar ($509/kW), wind ($504/kW), and storage projects ($437/kW) have higher interconnection costs than natural gas ($150/kW). Increased costs are driven by higher network costs – likely due to more remote points of interconnection.
- Cost differences narrow significantly when focusing only on completed studies (left dark bar) for solar ($216/kW), wind ($103/kW), and storage ($151/kW) (*but no recent natural gas projects completed all studies in our sample, making comparisons difficult*).
- Natural gas projects that have recently withdrawn from the interconnection queue do not seem to do so primarily for cost reasons ($219/kW), especially as projects that completed the study process in 2011-2017 have similar costs ($213/kW) [currently active projects have estimated costs of $107/kW] (see Appendix).



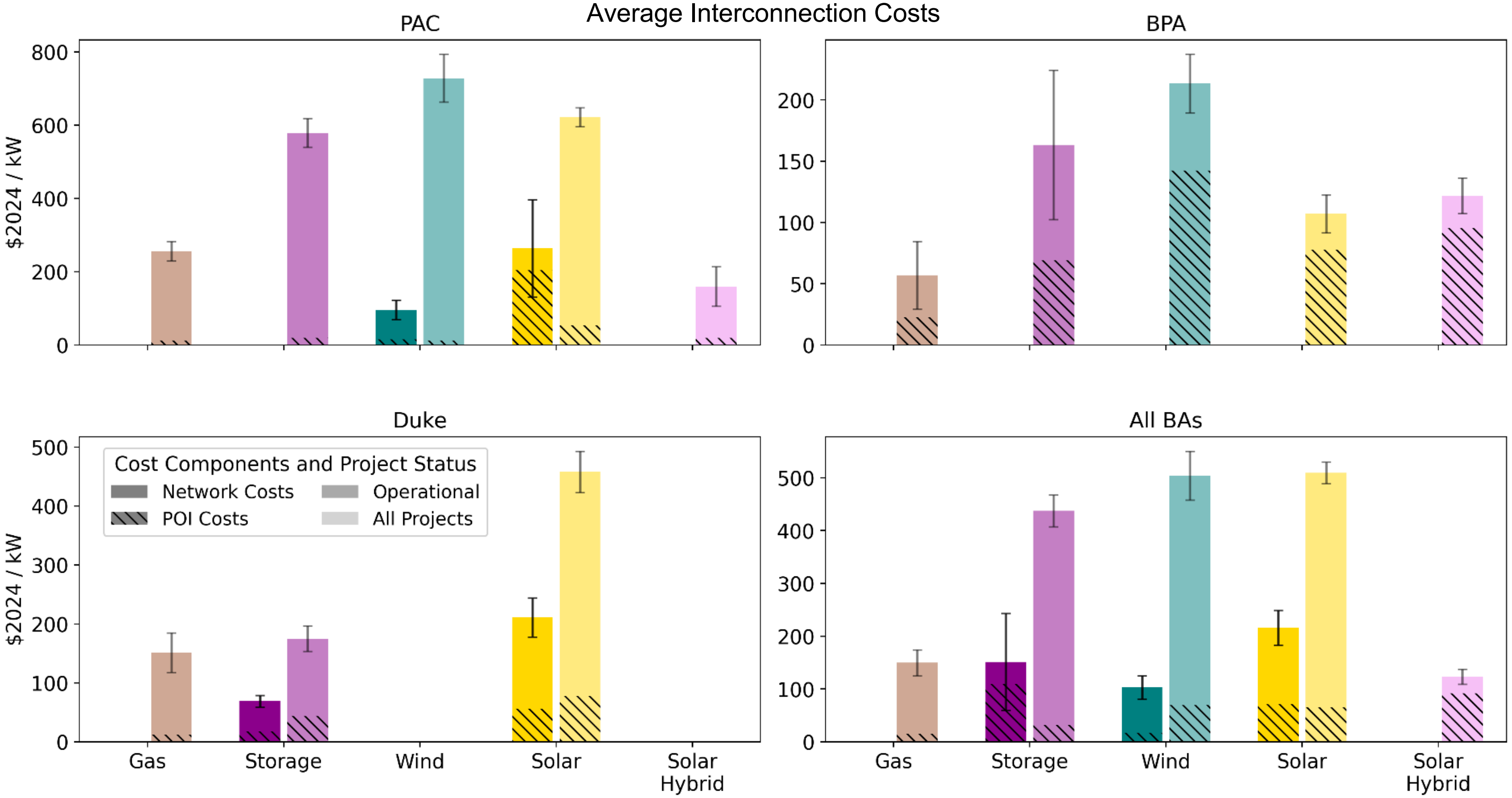
Averages represent 2018-2024 studies for complete (left) and all (right) projects.

Cost differences between BAs persist when accounting for fuel types

- PacifiCorp tends to have higher average interconnection costs than BPA or the Duke BAs for the same fuel type: among all recent interconnection requests, quoted costs were more than three times greater than wind in BPA or storage in BPA or Duke.

- However, interconnection costs for complete solar projects are more similar in PacifiCorp ($264/kW) and Duke ($211/kW).

- Few BPA projects studied between 2018 and 2024 have completed the interconnection process, but quoted costs for all requests are comparatively low and network upgrade costs play less of a role.



Averages represent 2018-2024 studies for complete (left) and all (right) projects.
Note that the y-axis scaling varies between subplots.

Case studies of recently proposed nuclear and geothermal projects

- **Nuclear:**
  - Existing PacifiCorp-owned Naughton coal plant in WY that is being converted to natural gas by 2026.
  - A new Natrium 345MW Gen IV nuclear reactor by TerraPower with sodium cooling and HALEU fuel is proposed at the same POI. It may have co-located molten-salt energy storage (100-500 MW with up to 5.5h duration) and can receive up to $2bn co-funding from DOE's Advanced Reactor Demonstration Project (ARDP).
  - It received construction permit for non-nuclear components in Jan 2025, awaiting nuclear permit from NRC with expected COD of 2030.
  - 2024 cluster study showed interconnection costs of $516/kW for request **C2-32** with 500 MW POI:
    - POI: $4.3MM (substation upgrades)
    - Network: $6.2MM Station Equipment, ERIS $199,116MM + NRIS $59,062MM

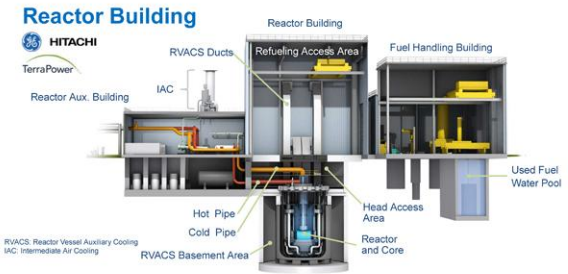


Image source: Nuclear Regulatory Commission

- **Geothermal:**
  - Significant interest to develop advanced geothermal systems in southwestern Utah.

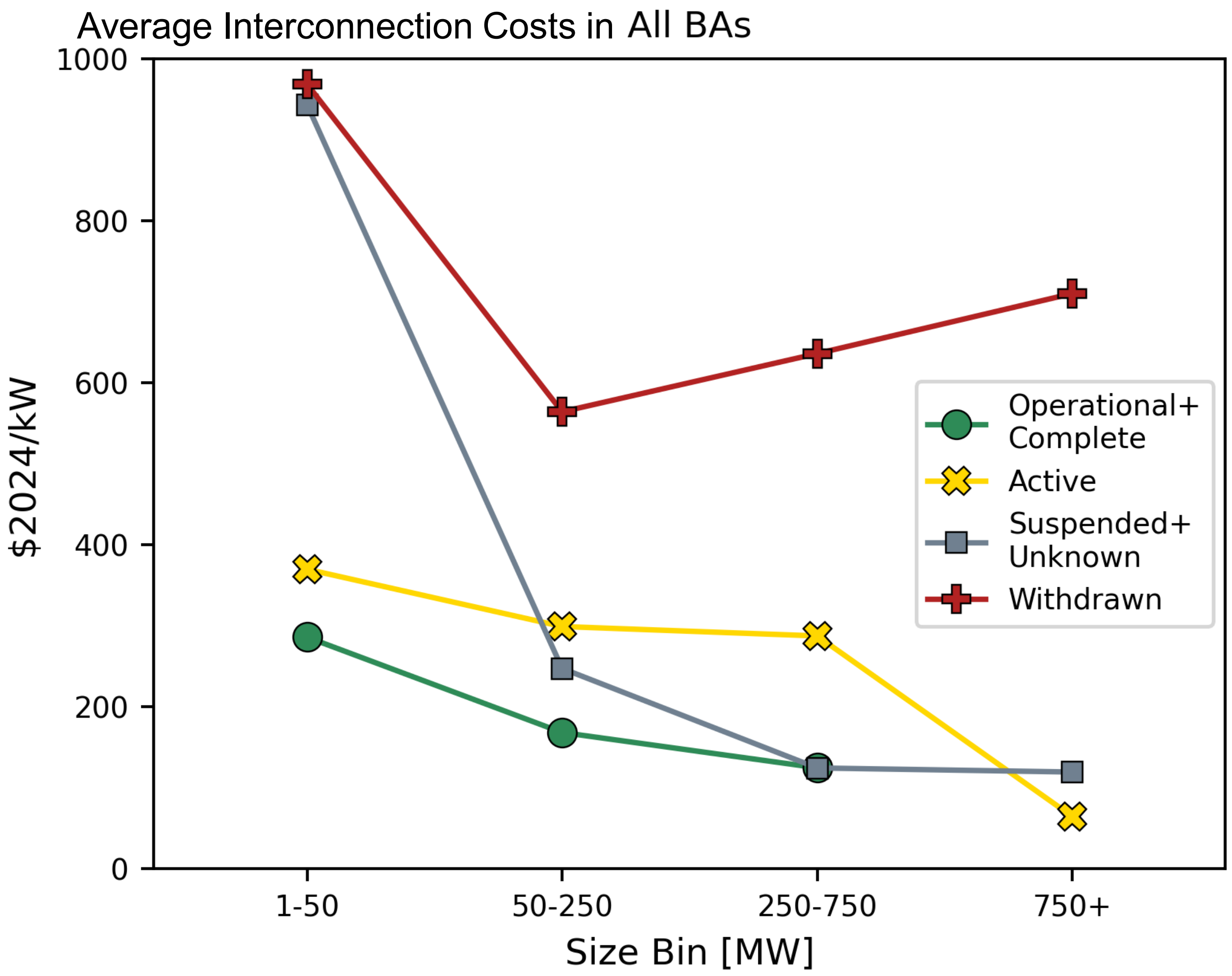
  2 recent requests in this area (PacifiCorp):
    - **C1-29**: 62 MVA turbine with 40 MW POI, COD 2025 in Beaver County, now withdrawn. 2021 cluster study estimated $417/kW (ERIS) or $500/kW (NRIS):
      - POI: $1.5MM
      - Network: ERIS: $14.98MM + NRIS $3.32MM
    - **C2-179**: 2 42MVA turbines with 40 MW POI, COD 2025 in Milard County, 2022 cluster study, still active with expected costs of $450/kW:
      - POI: $0.8MM (existing substation)
      - Network: $17.1MM (ERIS upgrade requirements are same as NRIS)

Image source: Utah Forge

Larger recent generators have lower interconnection costs per kW

- Projects with higher nameplate capacity have greater interconnection costs in absolute terms, but these costs do not scale linearly on a per kW basis.

- Looking at recent projects irrespective of request status, interconnection costs fall from $763/kW for small projects (1-50 MW), to $423kW (50-250 MW) and $426/kW (250-750 MW), and to $244/kW for very large projects (750+ MW).

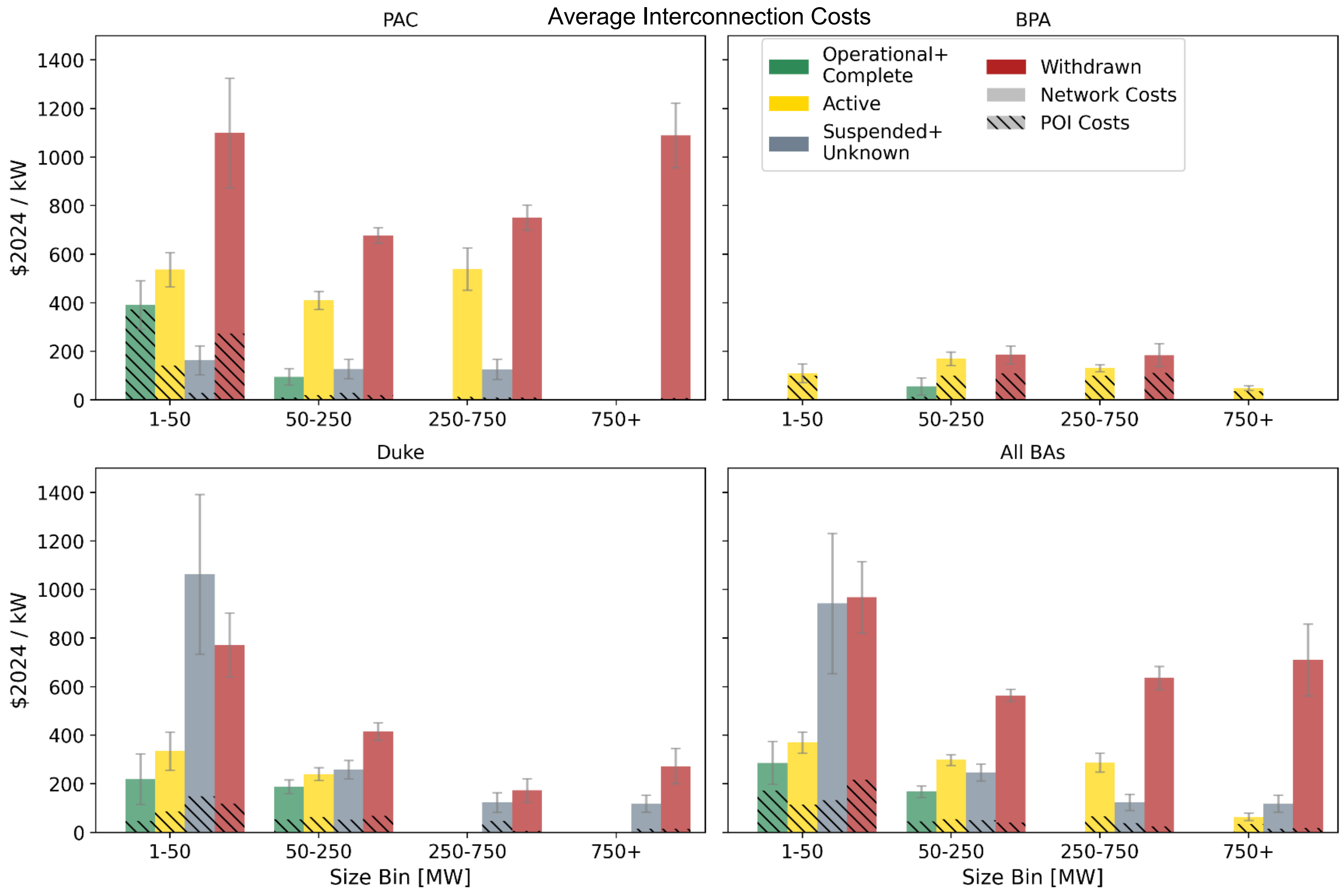


Averages only include studies performed in 2018-2024.

Economies of scale persist in all regions

- The general trend of declining costs with project size holds true across BAs and request statuses. While POI costs clearly play less of a role for large projects, the main driver are proportional decreases of network upgrade costs.

- Economies of scale are most apparent for solar and natural gas projects, less so for wind and storage.

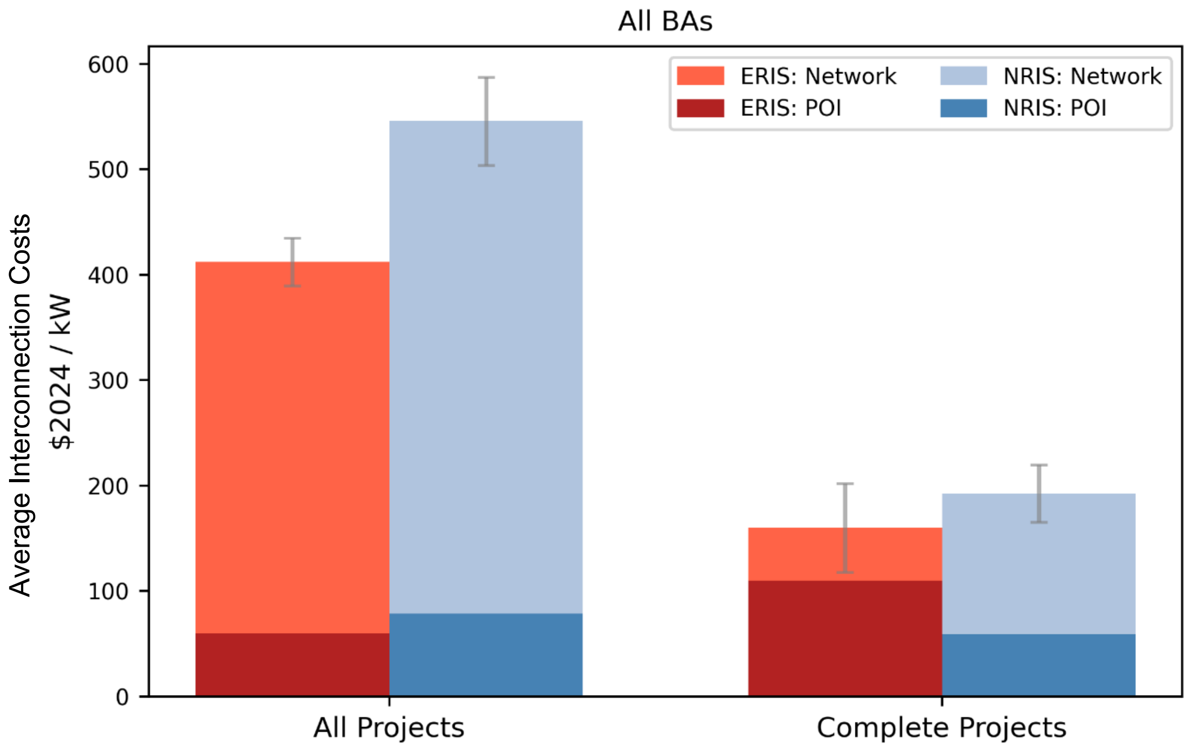


Averages represent studies performed in 2018-2024 studies and disregard earlier years.

Network upgrade costs are greater for capacity interconnection services

Interconnection Service Definitions

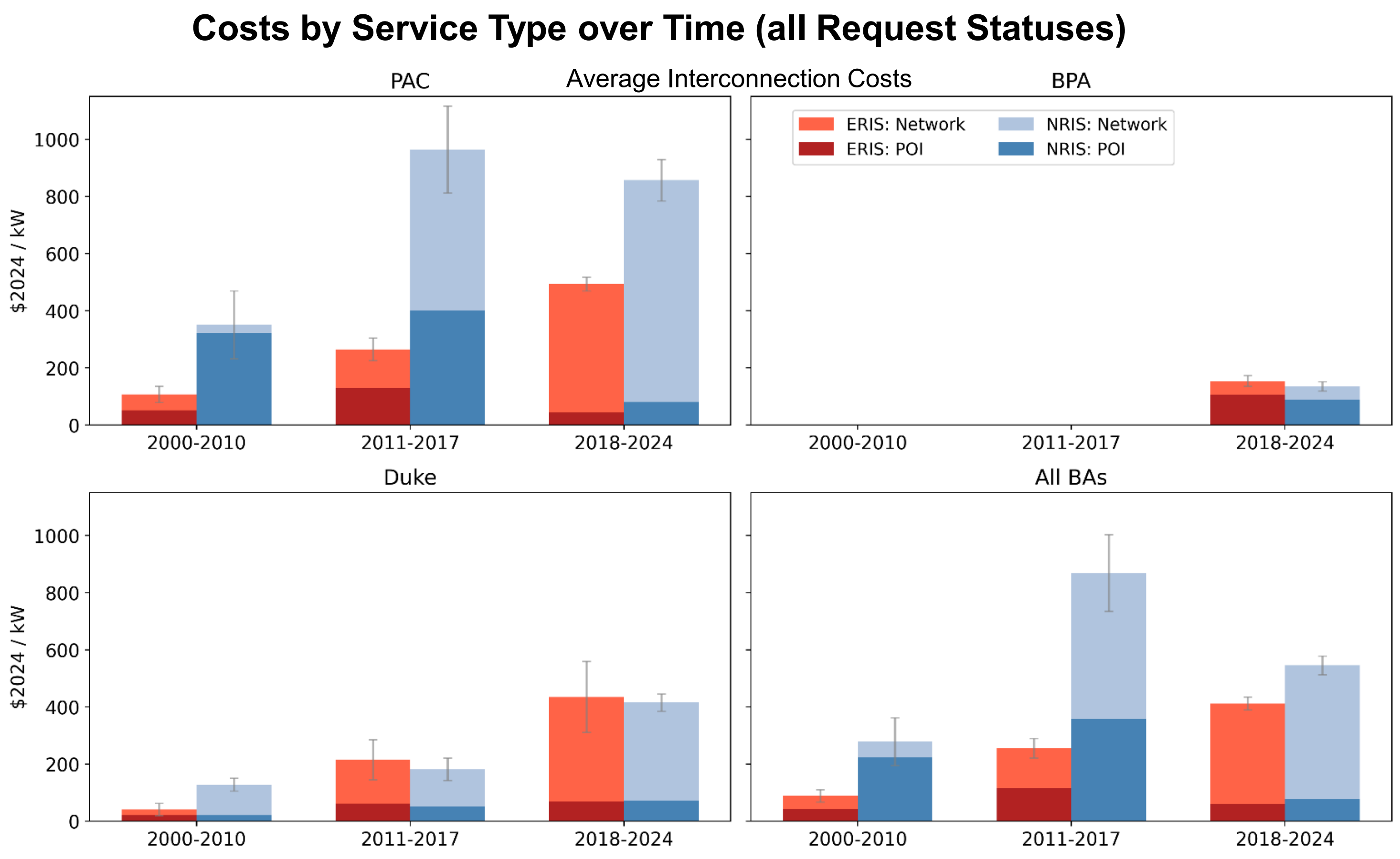
- Network resource interconnection service (NRIS): Comparable transmission access as existing generators by transmission provider to serve native load and count towards resource adequacy needs. May need to pay for additional transmission upgrades compared to ERIS.
- Energy resource interconnection service (ERIS): Deliver output using existing transmission capacity on an “as available” basis, no right to deliver electricity to specific customer.



Some applicants request joint “ERIS/NRIS” service and interconnection studies only return one cost estimate. We include these data points in both the ERIS and NRIS mean statistics.

- This graph shows interconnection costs by service type for recent studies (2018-2024). For all interconnection requests (left), network upgrades are more costly for NRIS service ($467/kW) compared to ERIS ($353/kW).
- Among recently completed projects (right), network upgrade costs are lower, but the NRIS premium persists ($133/kW for NRIS vs. $50/kW for ERIS).
- 37% of recent projects with cost data chose NRIS service, while another 32% requested joint ERIS/NRIS studies before finalizing their selection. This is about the same as in ISO markets, where 63% of 2018-2024 requests consider NRIS service.

BPA and Duke BAs do not seem to have network cost savings for ERIS among all interconnection requests



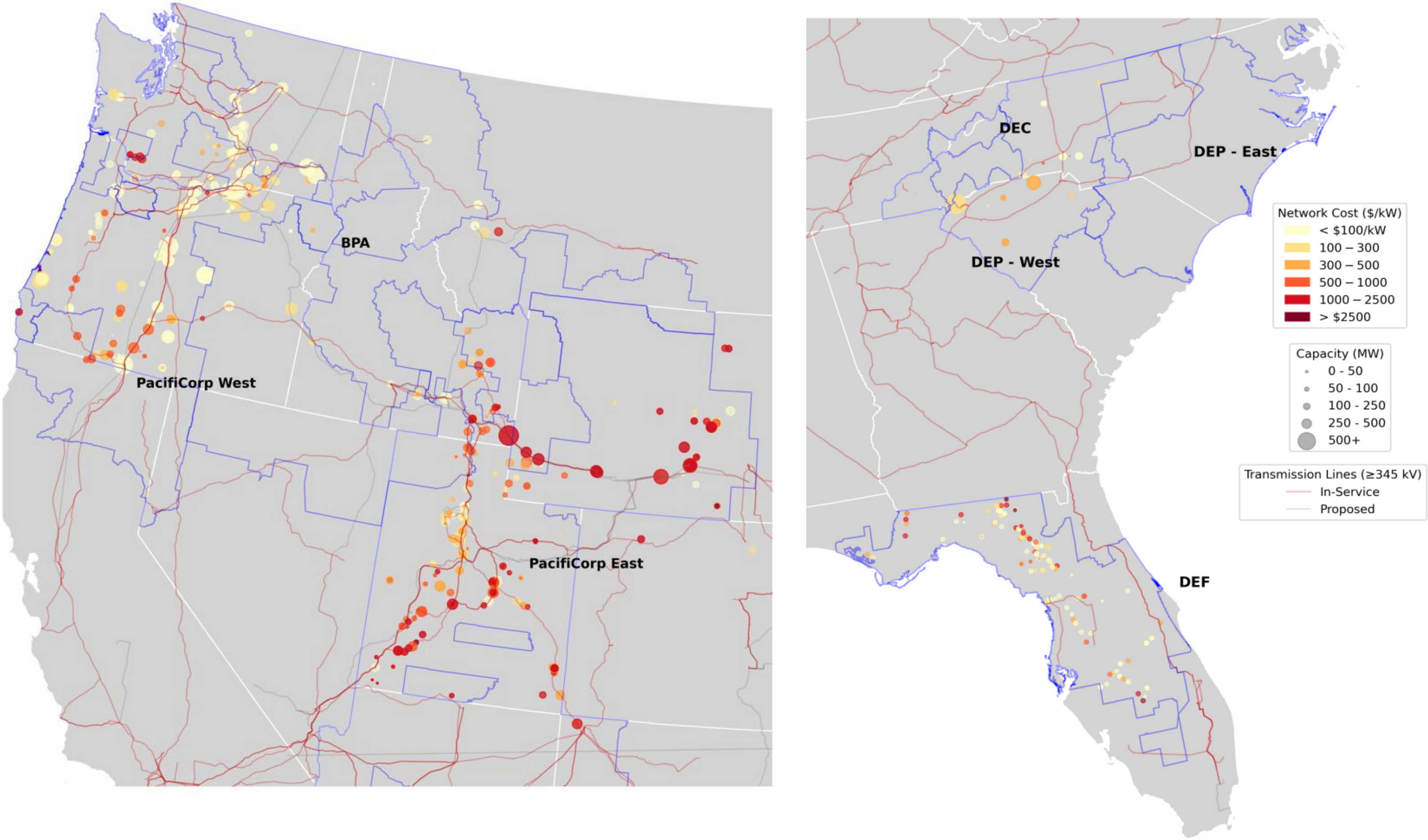
Averages include projects that withdraw interconnection applications and are higher than costs for "complete" projects. Some applications request joint "ERIS/NRIS" service and interconnection studies only return one cost estimate. We include these data points in both the ERIS and NRIS mean statistics.

- Network upgrade costs have increased over time for all interconnection service types in PacifiCorp and Duke BAs (no earlier cost data available for BPA).
- In PacifiCorp, projects requesting NRIS have substantially higher network upgrade costs compared to ERIS (172% in 2018–2024). Given the large PAC sample, this region dominates our "All BAs" statistics.
- However, across all interconnection requests in BPA and Duke, selecting the less robust ERIS ("as available" transmission) has not led to clear network upgrade cost savings compared to NRIS. When focusing only on recent studies of "complete" projects, we do find ERIS-associated savings in BPA and all Duke BAs (details in appendix).

Higher network upgrade costs are often geographically clustered

- The maps on the right show network upgrade costs. The location of recent interconnection requests are based on estimated POI coordinates. We distinguish projects by capacity (circle size) and network upgrade interconnection costs (color).

- Projects with high interconnection costs tend to be located along the same transmission lines, especially in southern Utah and Wyoming.

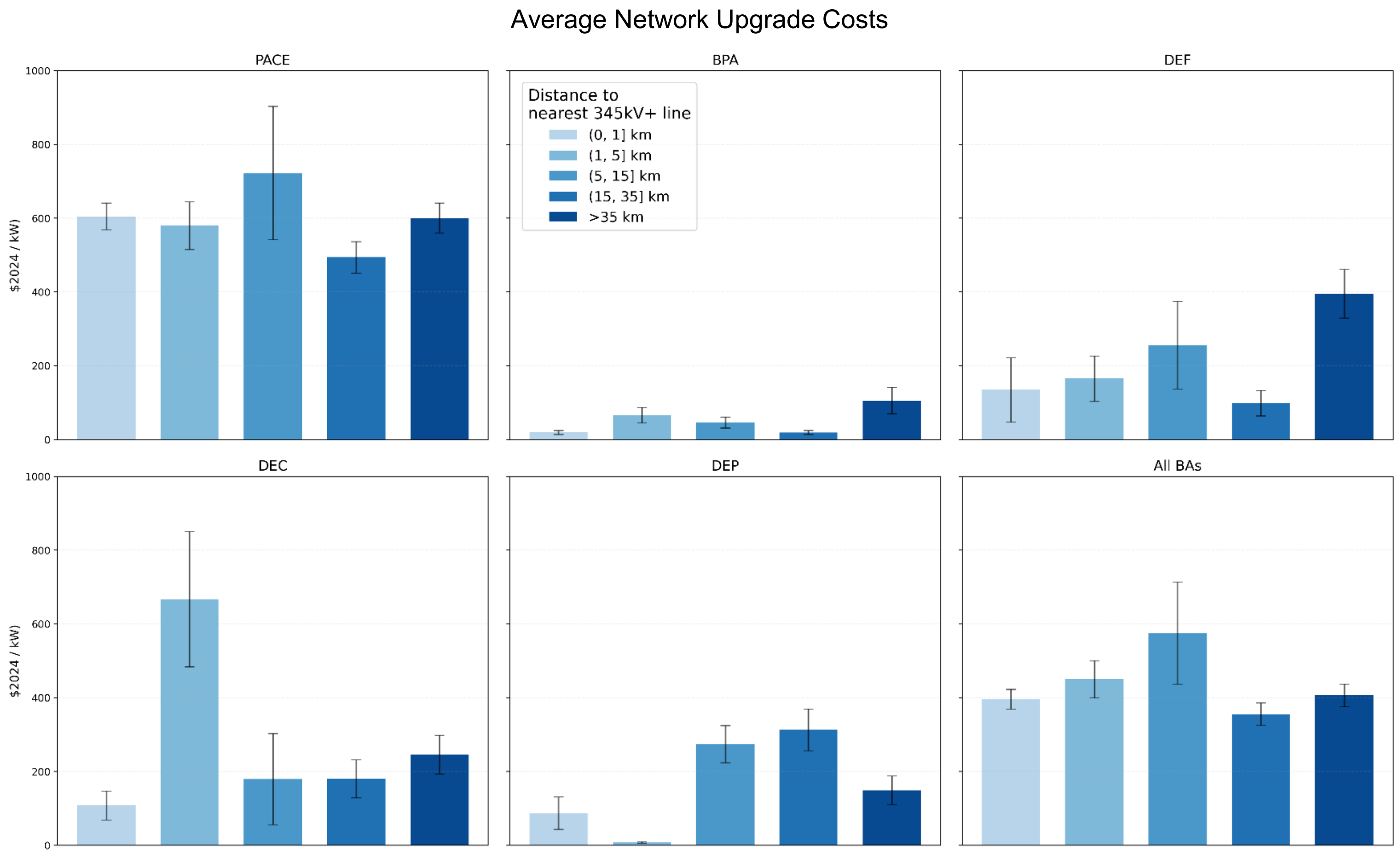


Depicted projects include those that withdraw interconnection applications. We only show network upgrade cost estimates from recent studies in our sample (2018-2024). POI coordinate estimates are based on contextual information of the interconnection studies, aided by satellite image analyses.

Distance between POI and high voltage transmission lines does not seem to be primary driver for network upgrade costs.

- Previous analyses for SPP and PJM showed a weak but persistent correlation between project/POI distance to high voltage (345kV+) transmission lines and network upgrade costs.

- We were not able to replicate these findings consistently in our non-ISO BA sample, either among recent (2018-2024, shown in graph) or all studies (2000-2024). The only BA with modest increasing cost trends by distance is DEF.



Conclusion

- **Background:**
  - Interconnection queues have tripled over the past four years in the five examined BAs, resulting in lengthy study processes with low completion rates (15%). FERC Order 2023 implementation will streamline the interconnection queue process, but results are not yet visible in the collected data.
  - Interconnection costs are not available as pre-request information and costs assessed in completed studies are challenging to collect. Developers engage in the interconnection process as a means of cost discovery and often withdraw projects with high interconnection costs. Providing greater expected cost transparency can focus developer efforts at a time of high expected load growth and aid overall system reliability.

- **Interconnection costs quoted to recent projects have increased compared to the early 2000s.**
  - Costs for projects that complete the interconnection study process have remained stable in some regions and grown in others. Active and withdrawn projects have greater costs. Network upgrade costs are the primary driver of recent cost increases, especially among withdrawing projects.

- **Recent interconnection costs in our non-ISO Balancing Authorities sample are higher than in ISOs**
  - Developers in non-ISO BAs seem to have higher willingness to pay as recent projects that complete all studies have double the interconnection costs. Network costs explain most cost differences.

- **Interconnection costs vary across multiple categories:**
  - Recent quoted costs for solar, onshore wind, and storage are higher than for natural gas projects, but cost differences diminish among projects that complete the study process.
  - Recent larger generators have lower proportional costs.
  - Firmer interconnection service (NRIS) comes with greater costs than “as available” transmission capacity (ERIS).
  - High network upgrade costs are often clustered geographically.

Engage in the i2X program to help inform potential solutions:
Forum for the Implementation of Reliability Standards for Transmission (FIRST) webinars

Contacts

Joachim Seel: jseel@lbl.gov, 510-486-5087

For more information

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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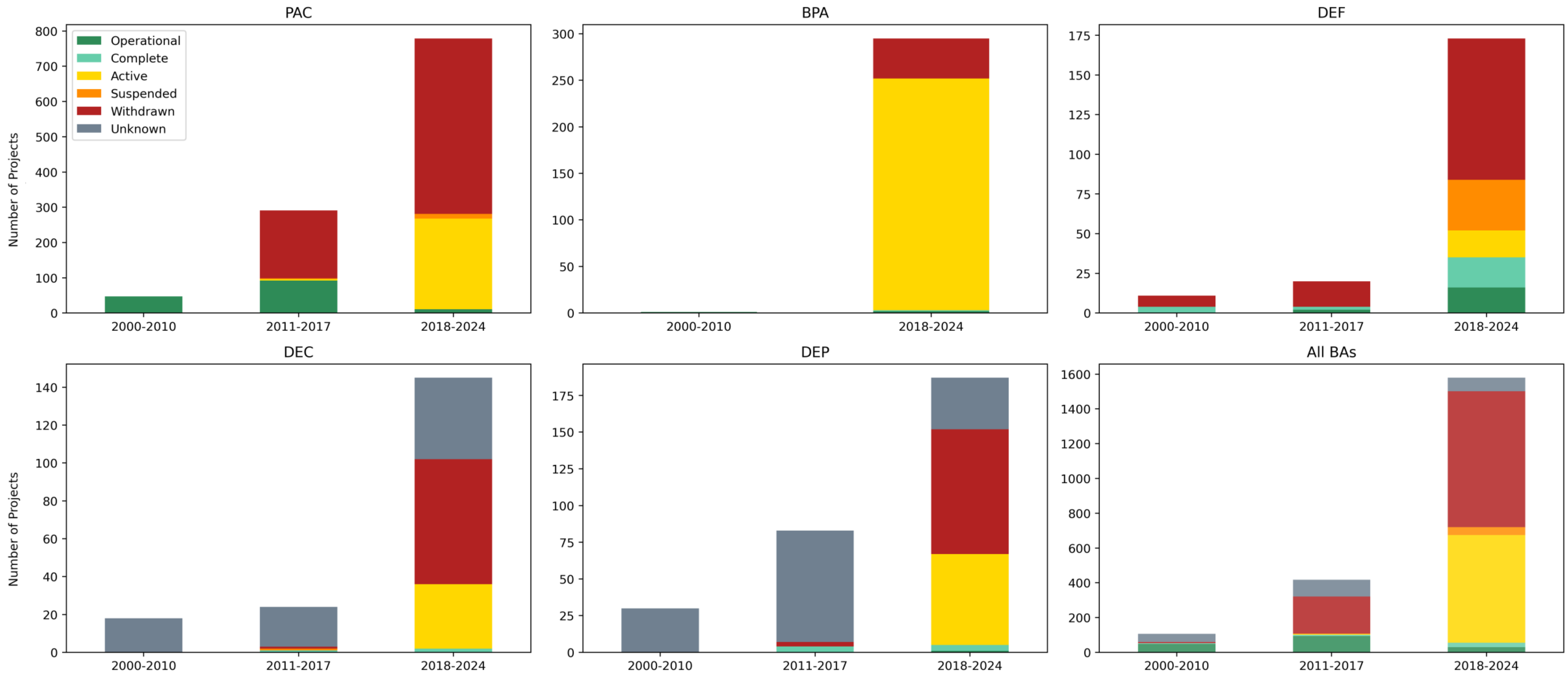
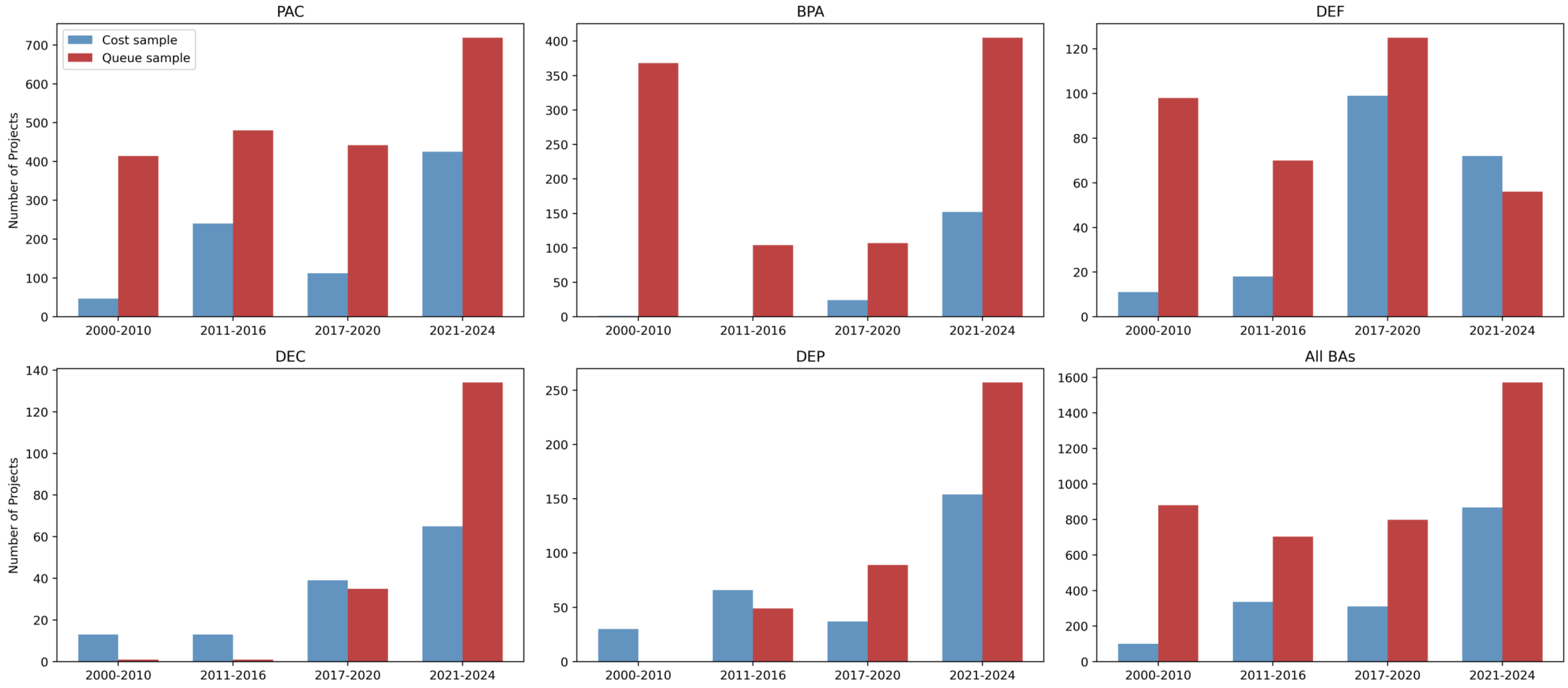
Appendix

Interconnection cost sample by BA



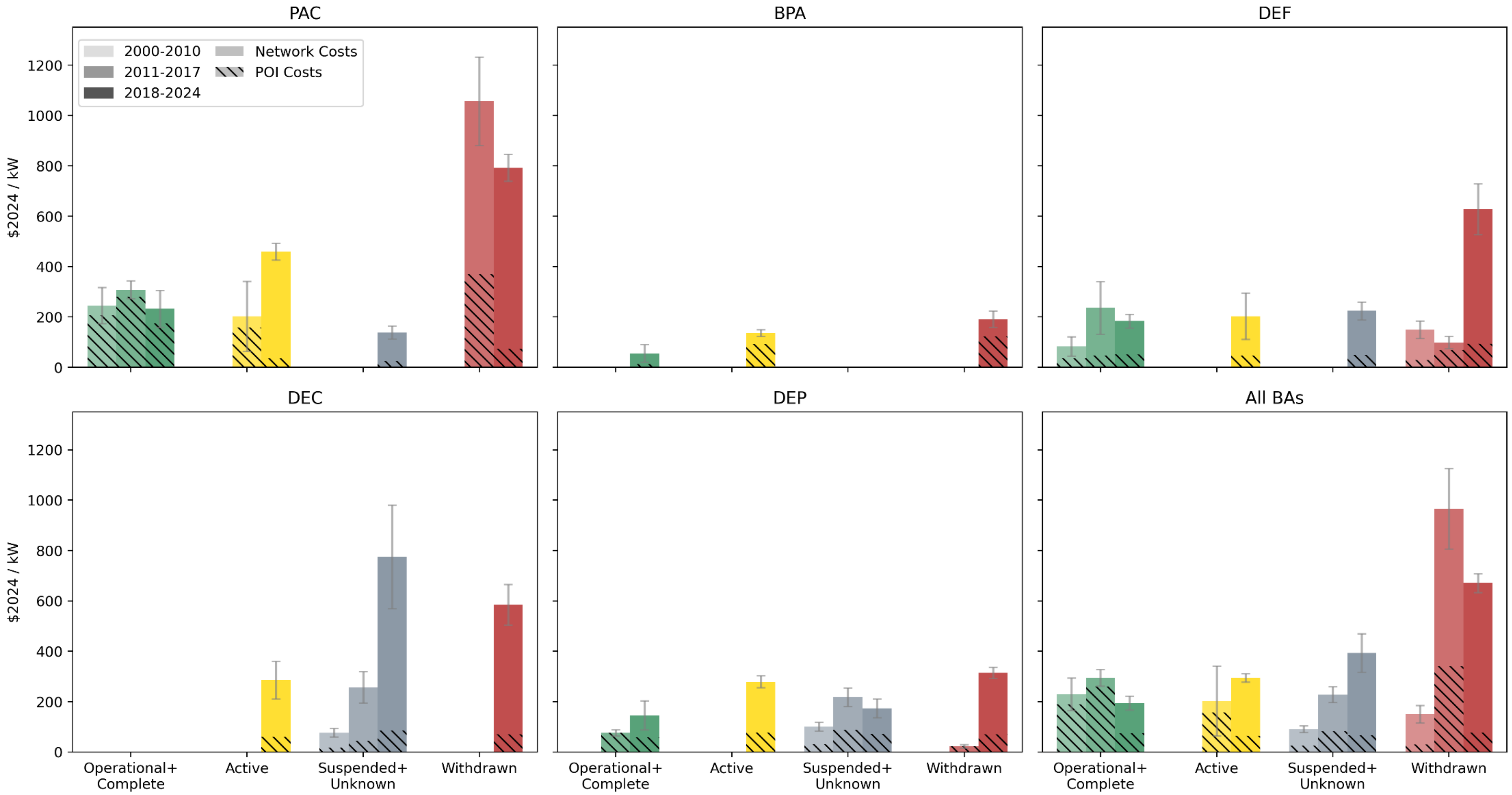
Note that the y-axis scaling varies between subplots.

Interconnection cost sample vs interconnection queues by BA



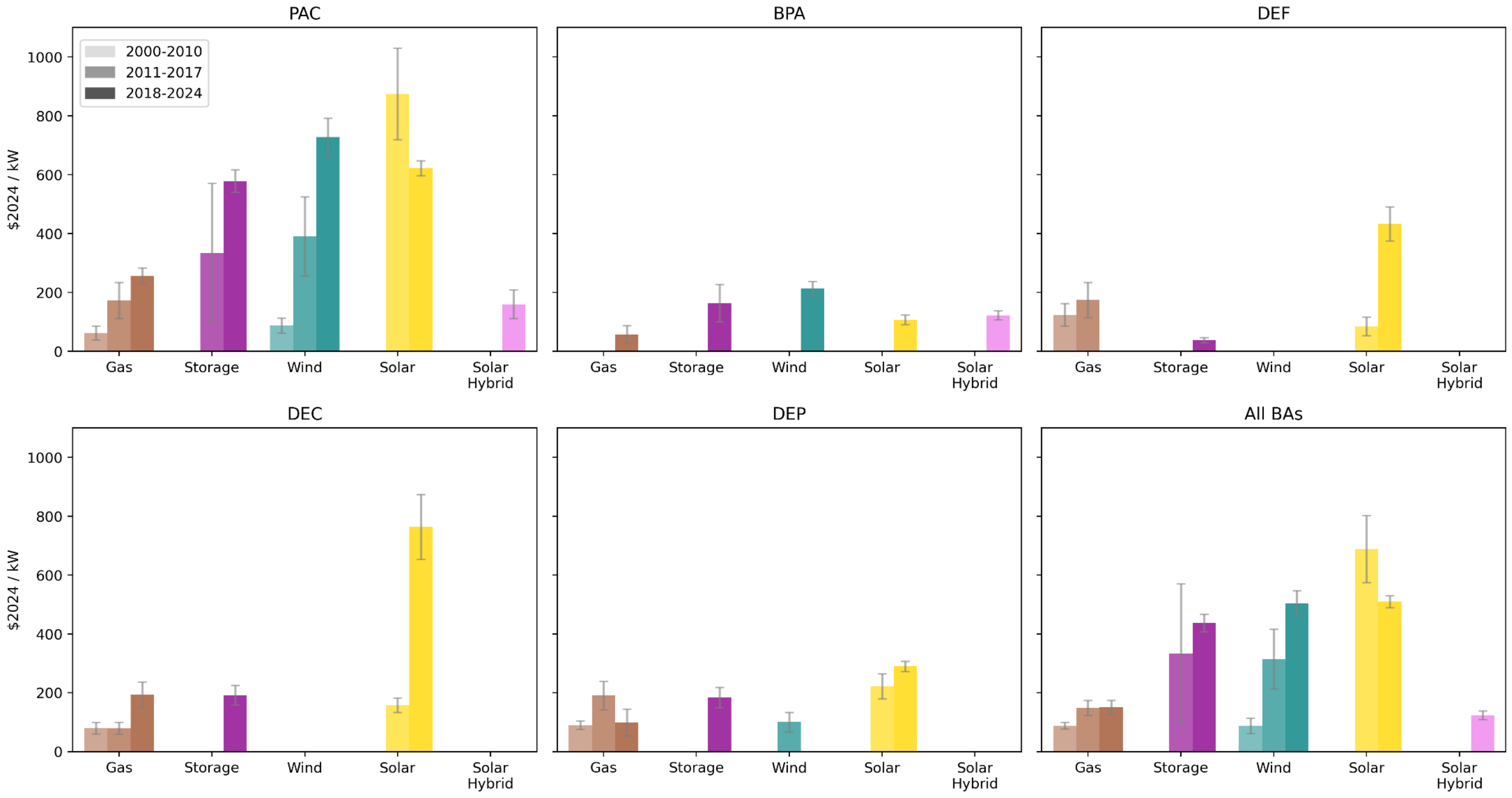
Note that the y-axis scaling varies between subplots.

Interconnection cost over time by request status, cost category, and BA

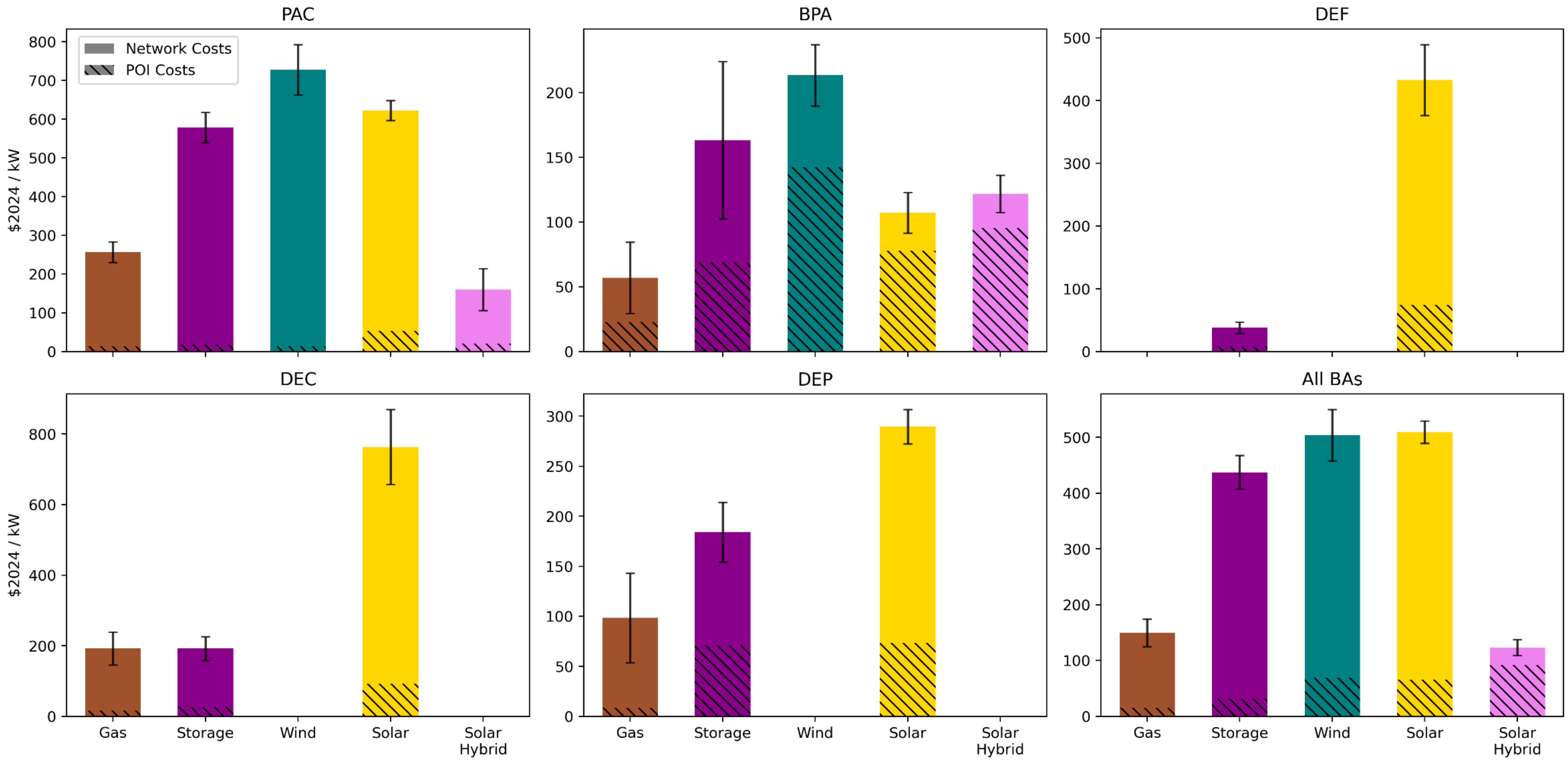


Interconnection cost categories are not consistently defined by each BA and require some judgement during data collection process.

Interconnection cost over time by fuel type and BA

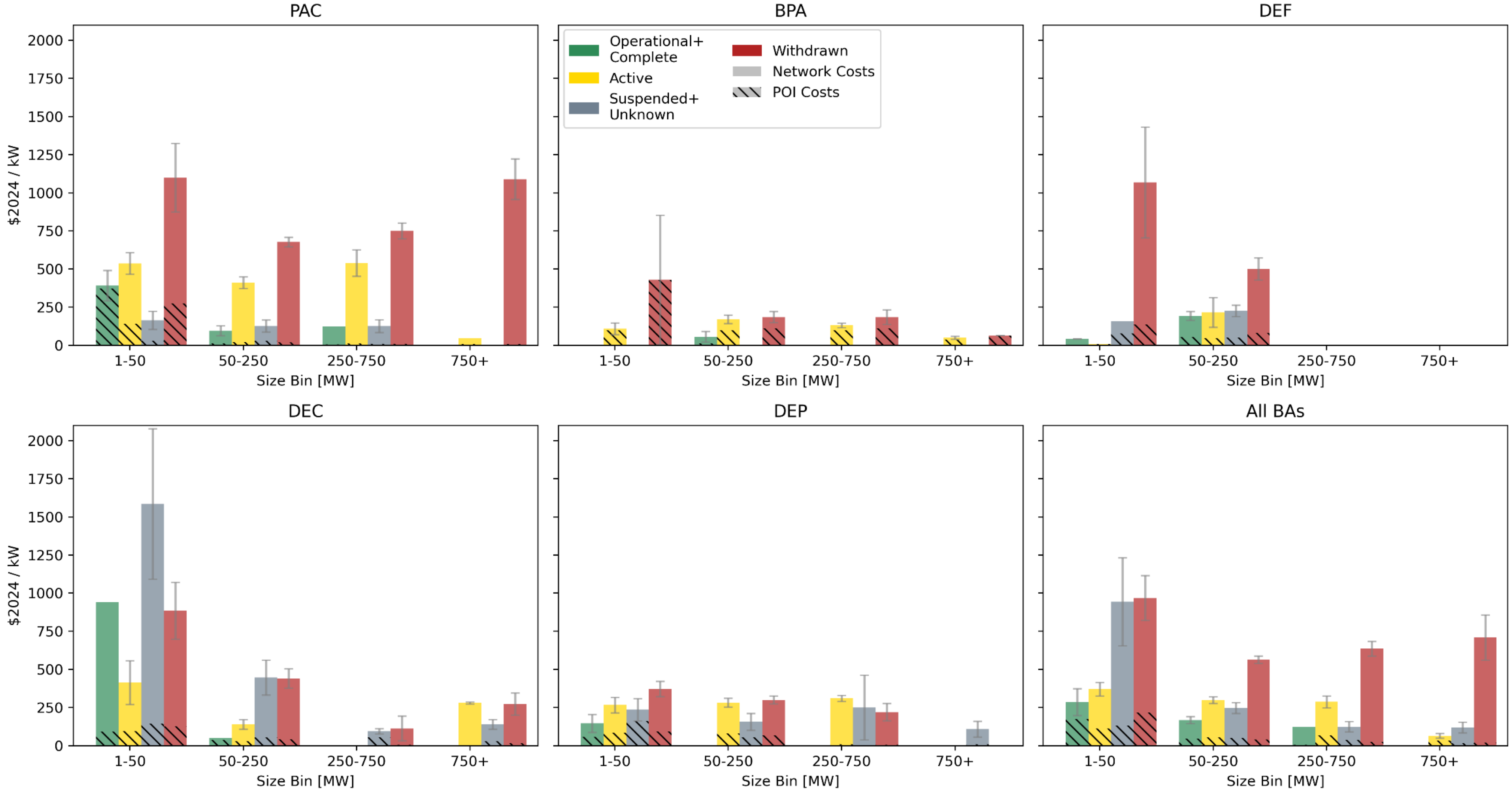


Interconnection cost by fuel type, cost category, and BA



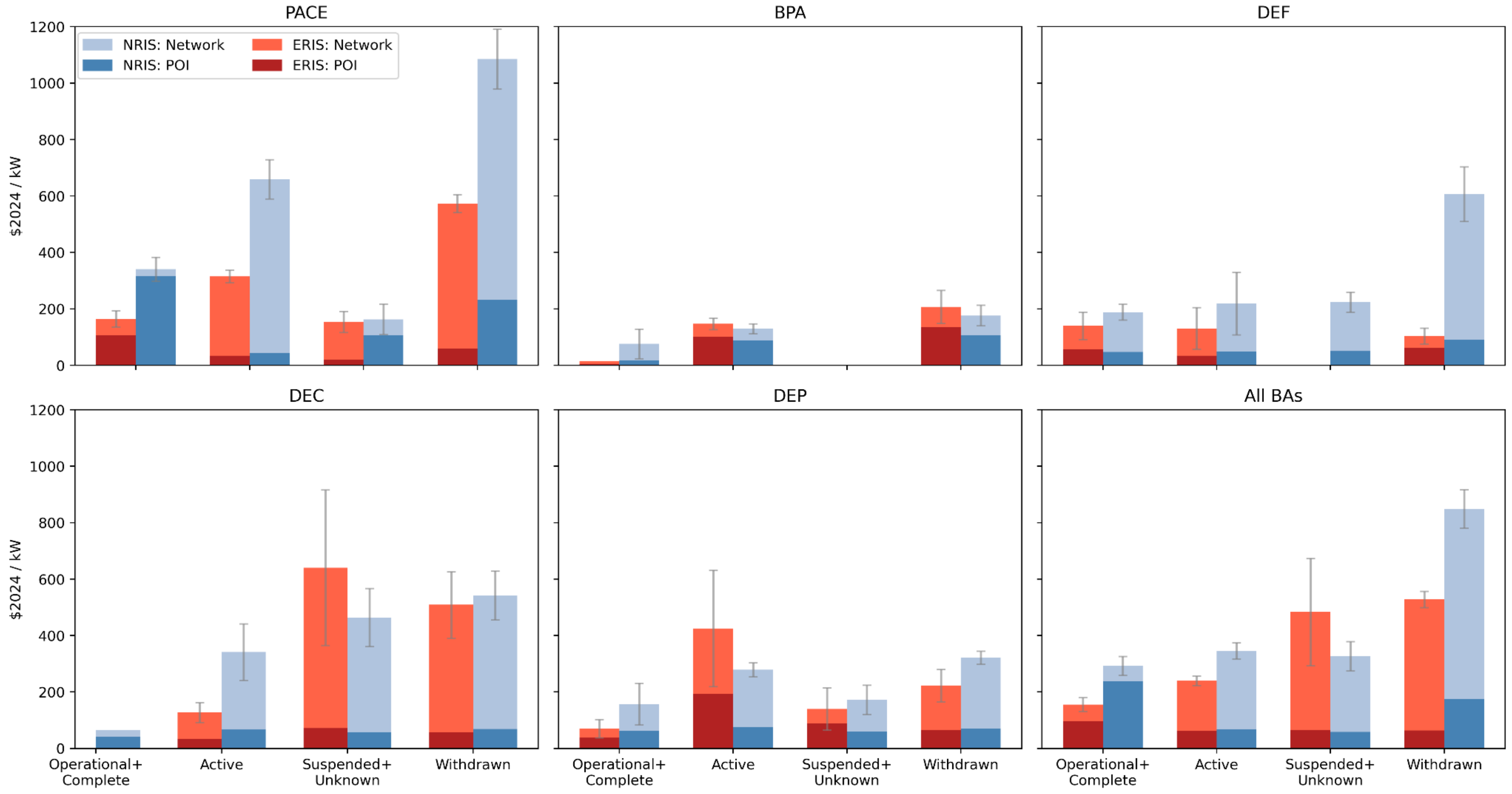
Averages represent 2018-2024 studies for all projects. Note that the y-axis scaling varies between subplots.

Interconnection cost by project capacity, request status, and BA

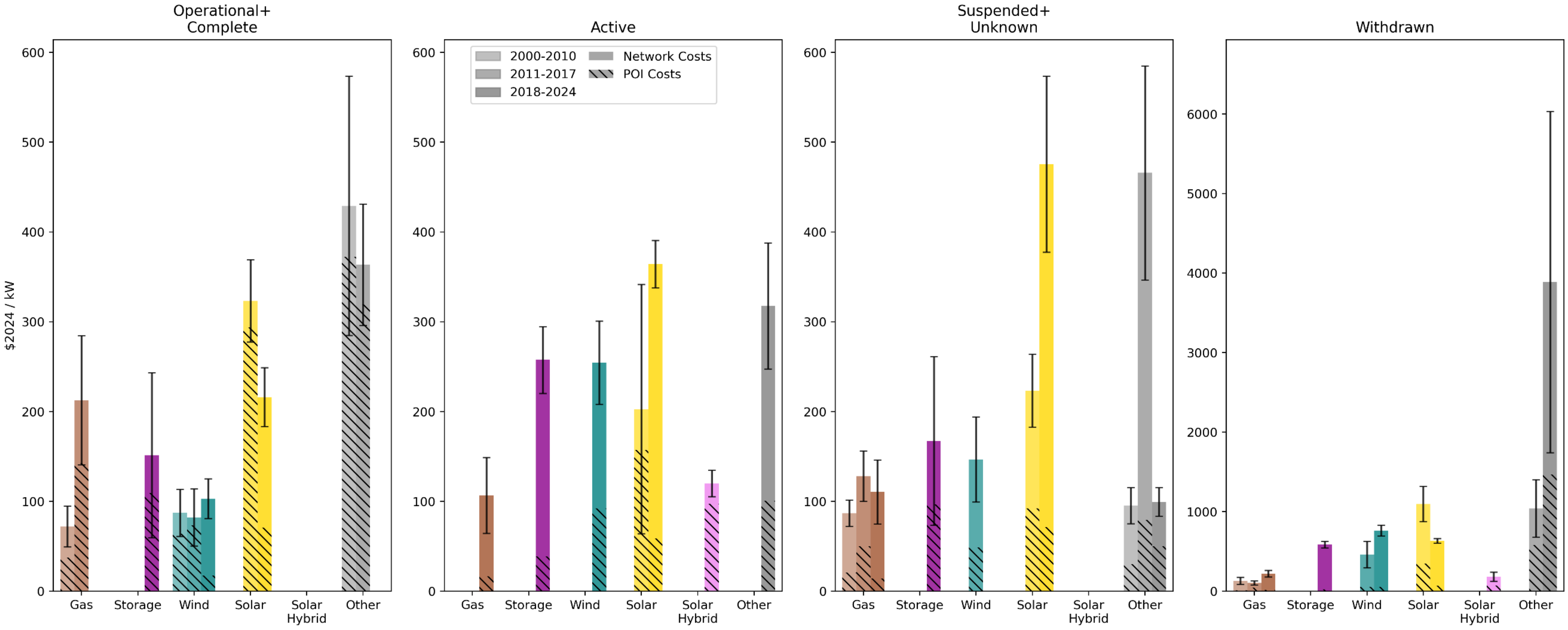


Averages represent studies performed in 2018-2024 studies and disregard earlier years.

Interconnection costs by service type, request status, cost category, and BA among recent studies (2018-2024)

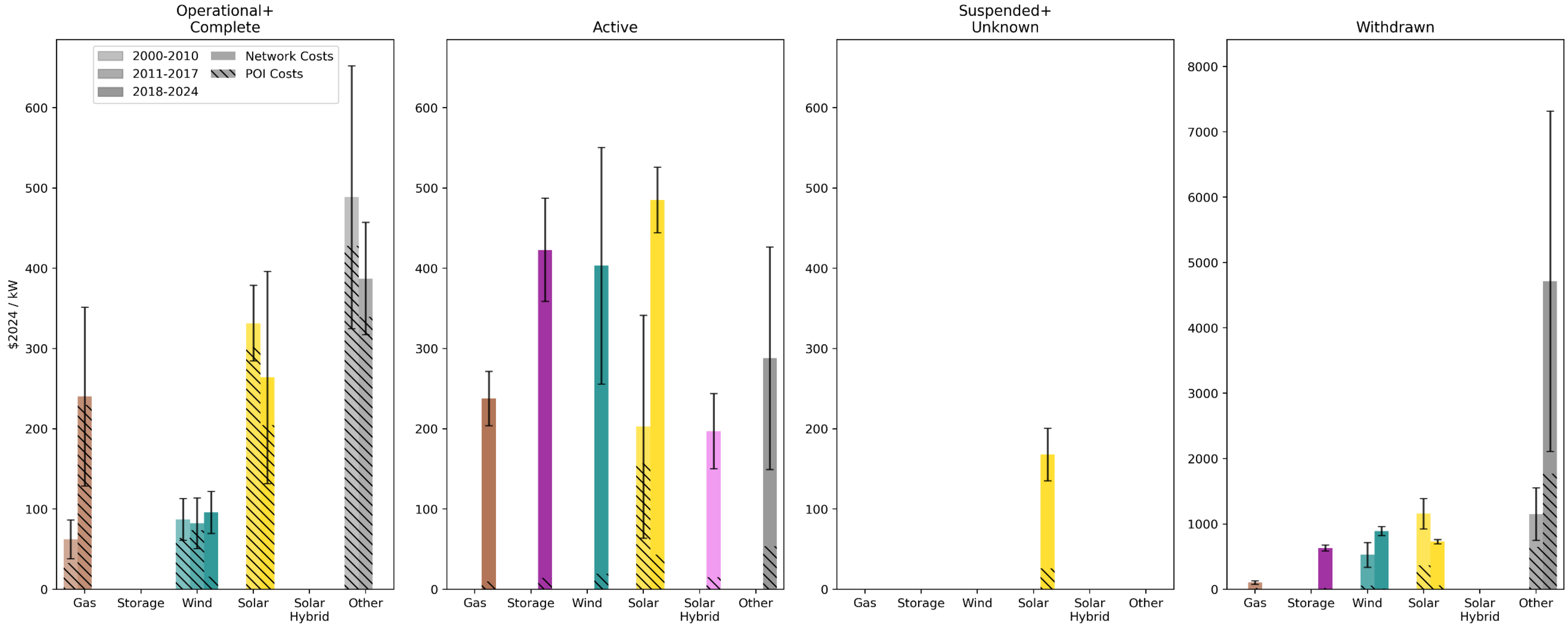


Interconnection costs by request status, fuel type, time, and cost type – All BAs



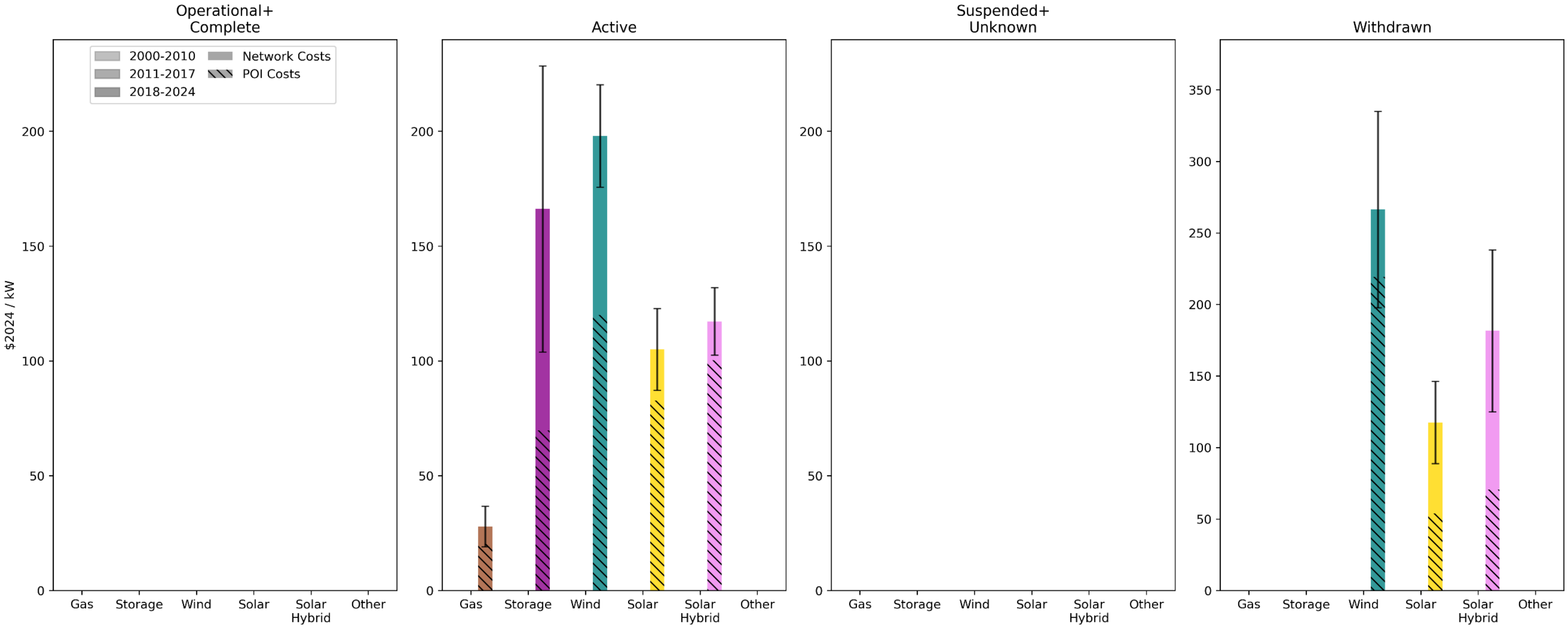
We exclude bars with three or fewer observations. Note that the y-axis scaling varies between subplots.

Interconnection costs by request status, fuel type, time, and cost type - PAC



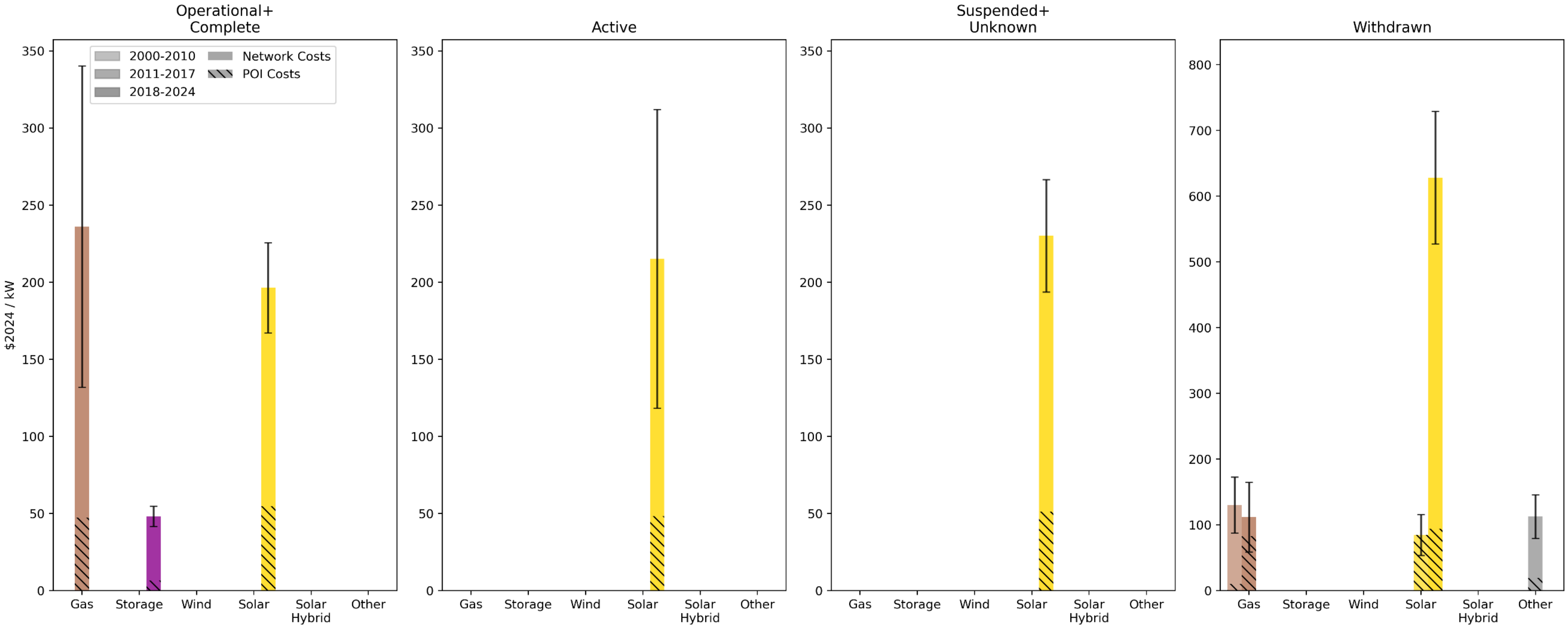
We exclude bars with three or fewer observations. Note that the y-axis scaling varies between subplots.

Interconnection costs by request status, fuel type, time, and cost type - BPA



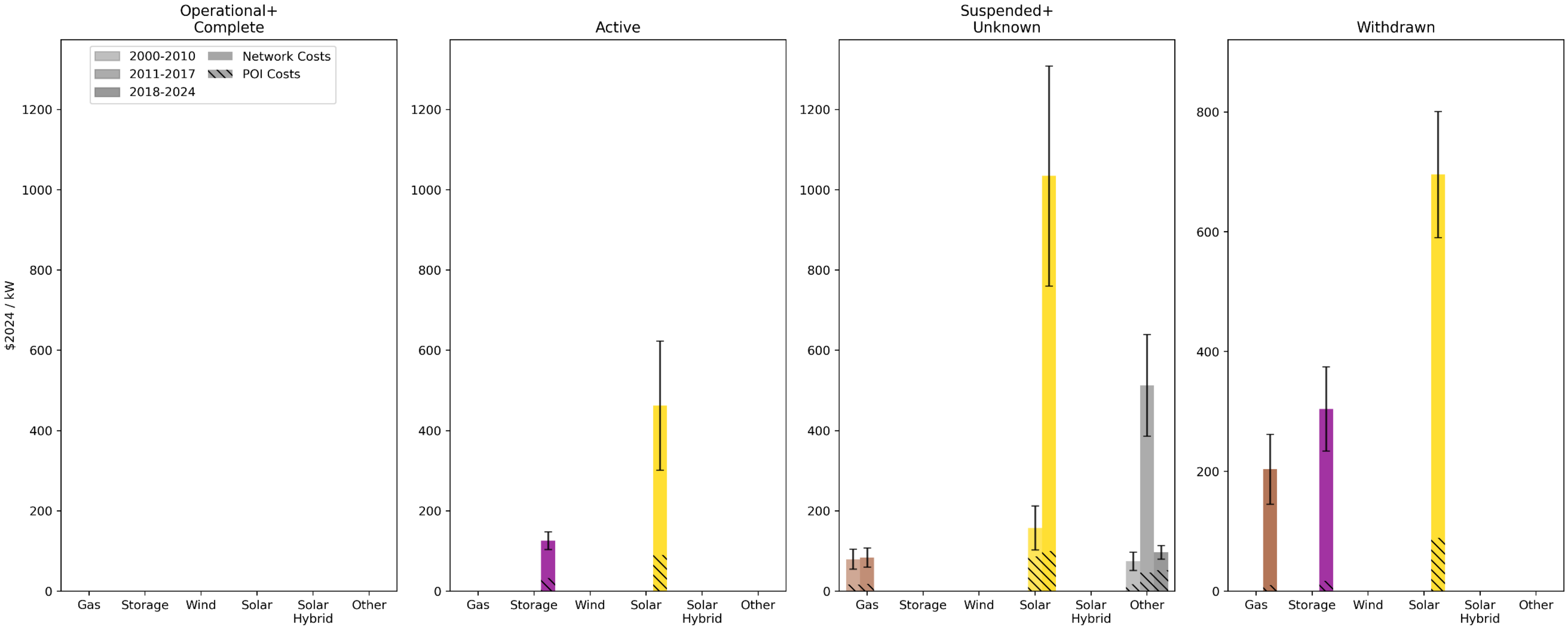
We exclude bars with three or fewer observations. Note that the y-axis scaling varies between subplots.

Interconnection costs by request status, fuel type, time, and cost type - DEF



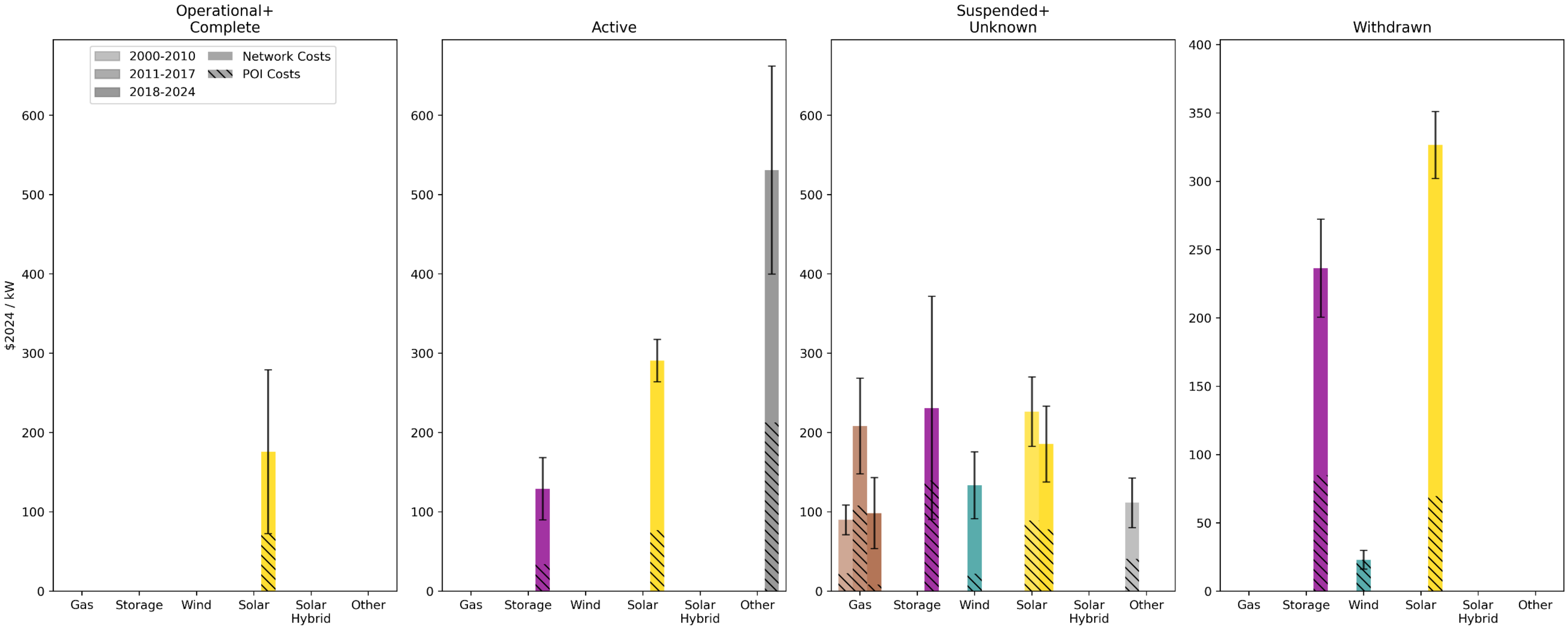
We exclude bars with three or fewer observations. Note that the y-axis scaling varies between subplots.

Interconnection costs by request status, fuel type, time, and cost type - DEC



We exclude bars with three or fewer observations. Note that the y-axis scaling varies between subplots.

Interconnection costs by request status, fuel type, time, and cost type - DEP



We exclude bars with three or fewer observations. Note that the y-axis scaling varies between subplots.