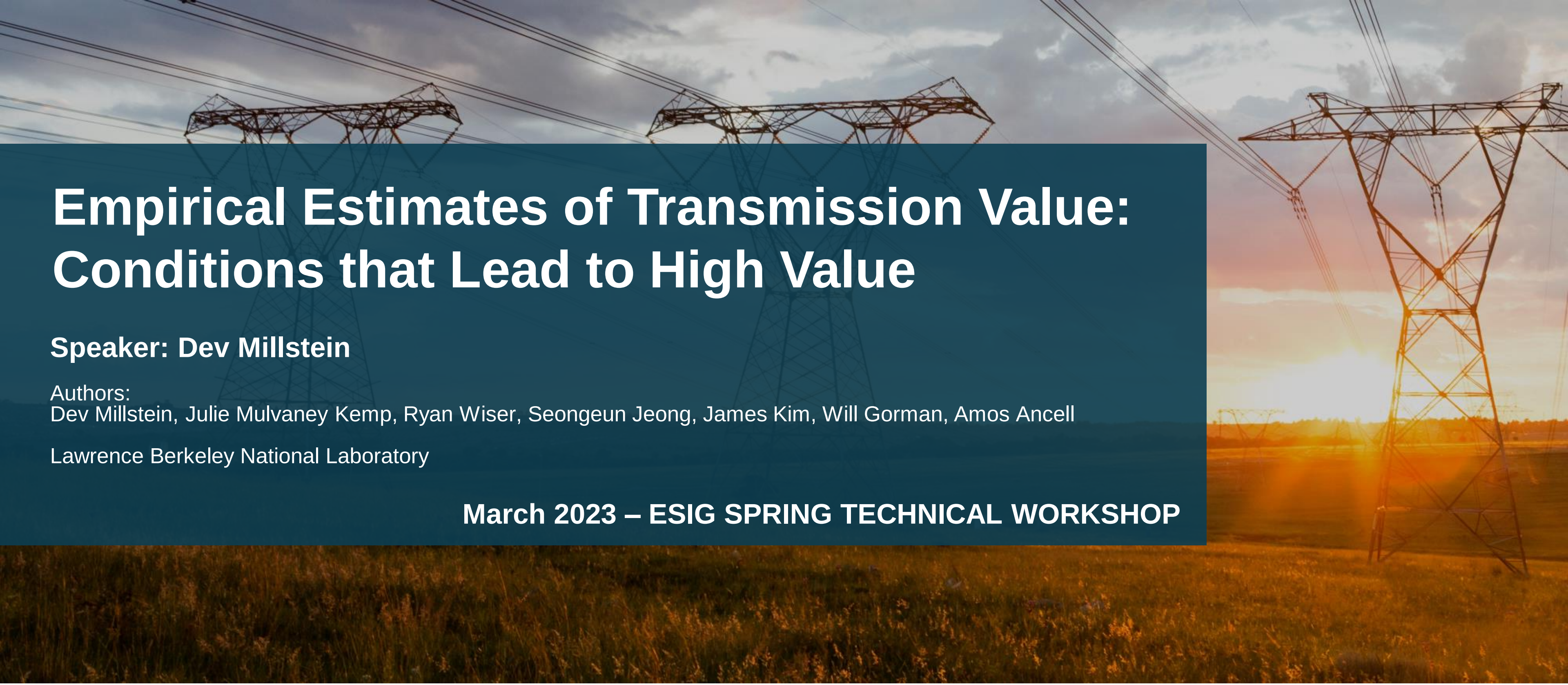

Empirical Estimates of Transmission Value: Conditions that Lead to High Value

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Outline

- **Introduction and Motivation**
  - Goals and scope
  - Approach
- **Results**
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  - Transmission value
  - Transmission value during extreme events and high-value hours
  - Comparison to modeled transmission value
- **Conclusion**
  - Key conclusions
  - Interpretation
  - Key limitations

Introduction and motivation

- Transmission can help reduce the system-wide costs of supplying electricity and can also improve grid reliability and resiliency
- Build decisions depend on the cost benefit tradeoffs
- **An important challenge in transmission planning and coordination is estimating the full range of benefits that transmission investments provide**
- This study focuses on a subset of total transmission value – congestion value – because there is concern in the literature that congestion value is often underestimated in transmission planning studies
- Congestion value is related to production cost savings, which is an important component of total transmission benefits (roughly half) and is a commonly estimated benefit of transmission
- By using empirical data, our analysis accounts for transmission benefits inclusive of extreme weather and other high value conditions (e.g., generator or infrastructure outages, forecast uncertainty, etc.)
- Forward-looking models of production cost and congestion savings are challenged in projecting value during more extreme weather conditions and other high value conditions

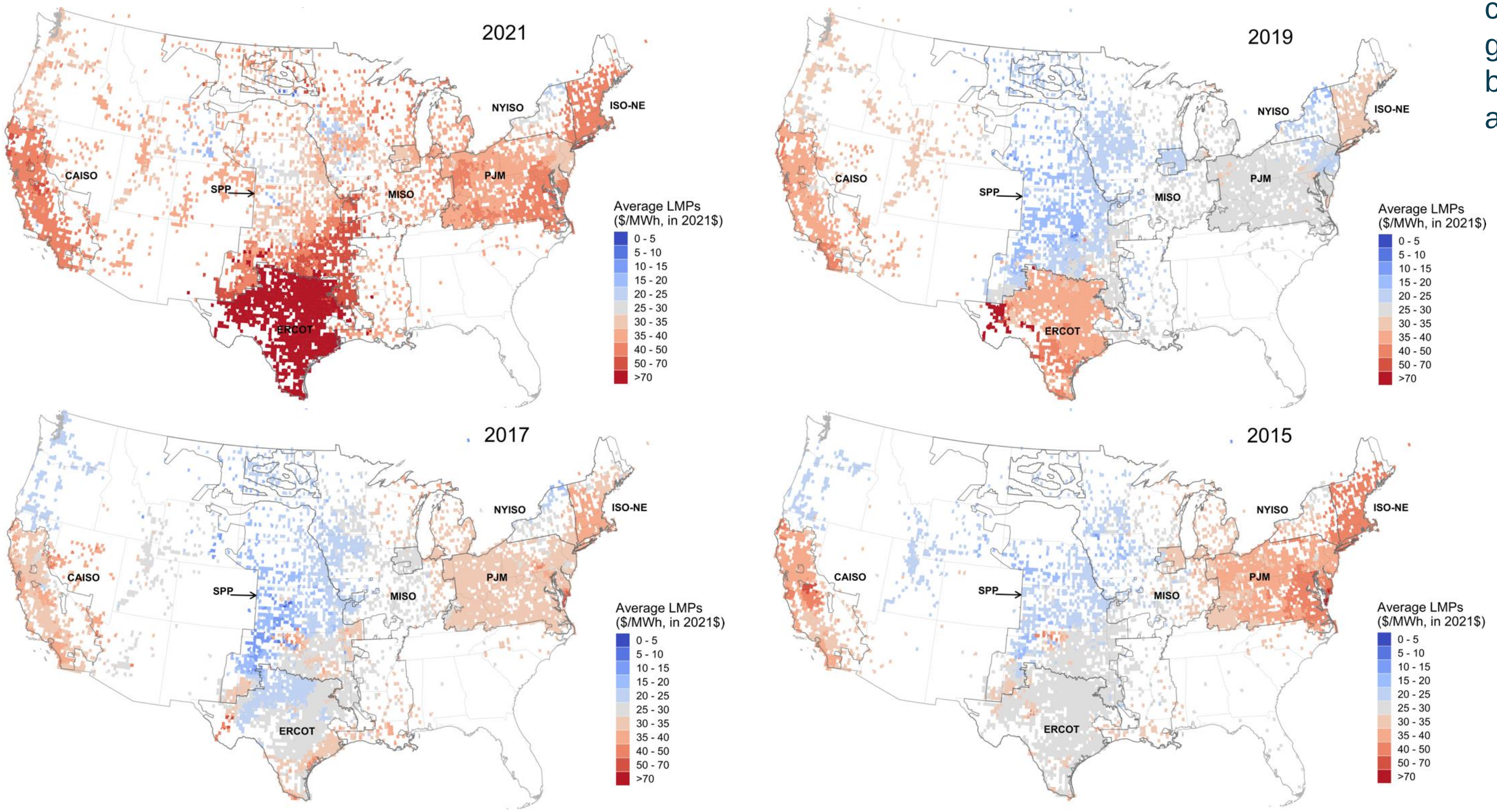
Approach: Analyze local hourly electricity prices

- Differences in real-time nodal electricity prices (LMPs) indicate transmission congestion value

- Key limitations:
  - Pricing differentials only represent a portion of total transmission benefits
  - Historical values do not necessarily reflect values under changing or future market conditions
  - LMPs are “marginal” prices, thus calculated transmission values are subject to saturation effects
  - LMPs are from energy markets, and benefit estimates do not include capacity market value
  - Some differences in pricing between regions is due to differences in market rules and structure rather than lack of transmission
  - A small portion of LMP differences are due to electrical losses rather than congestion

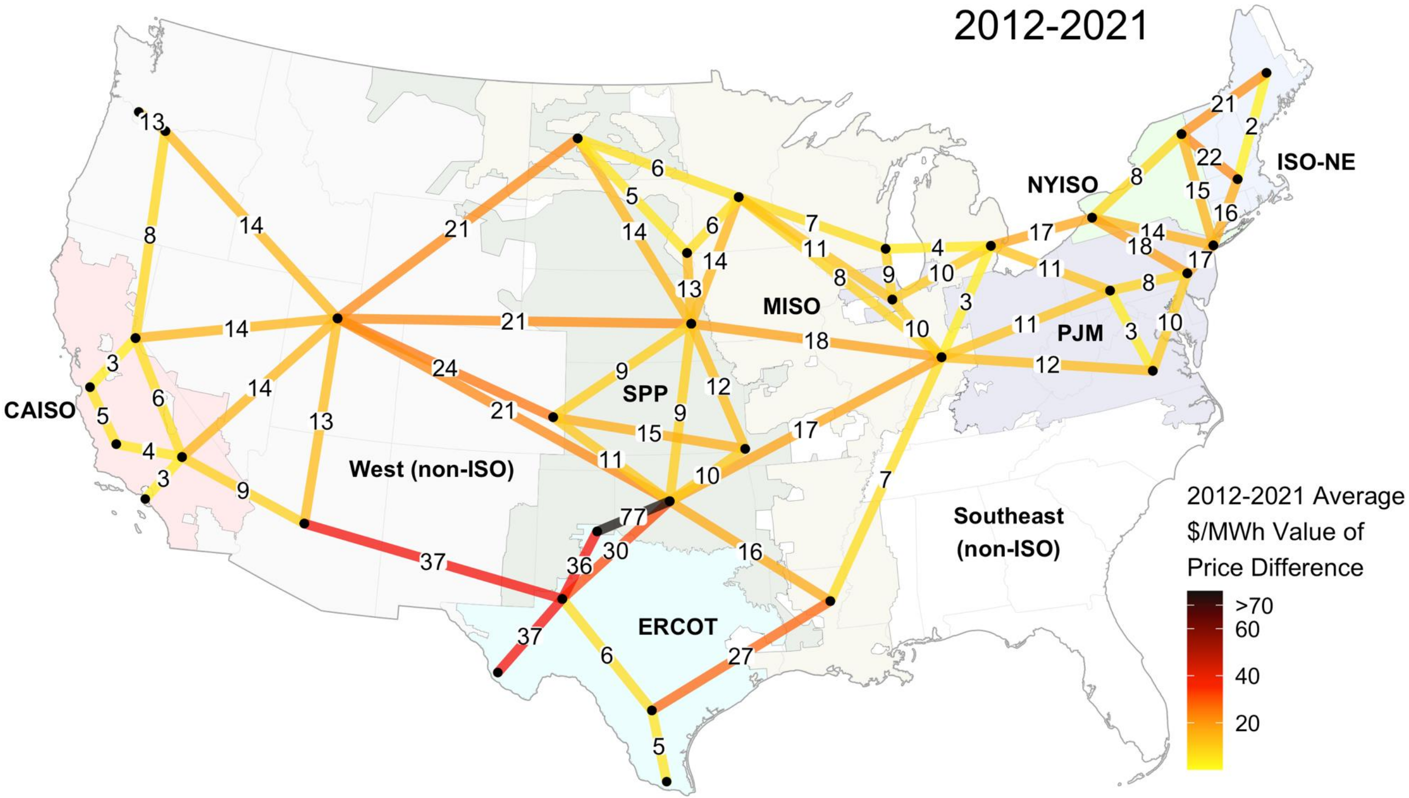
Estimating Transmission Value with Locational (Nodal) Market Prices (LMPs)

Context: Annual average real-time nodal wholesale electricity prices vary strongly by year and location



Beyond the clear difference in price between years, one can observe spatial gradients in prices both within regions and across regions

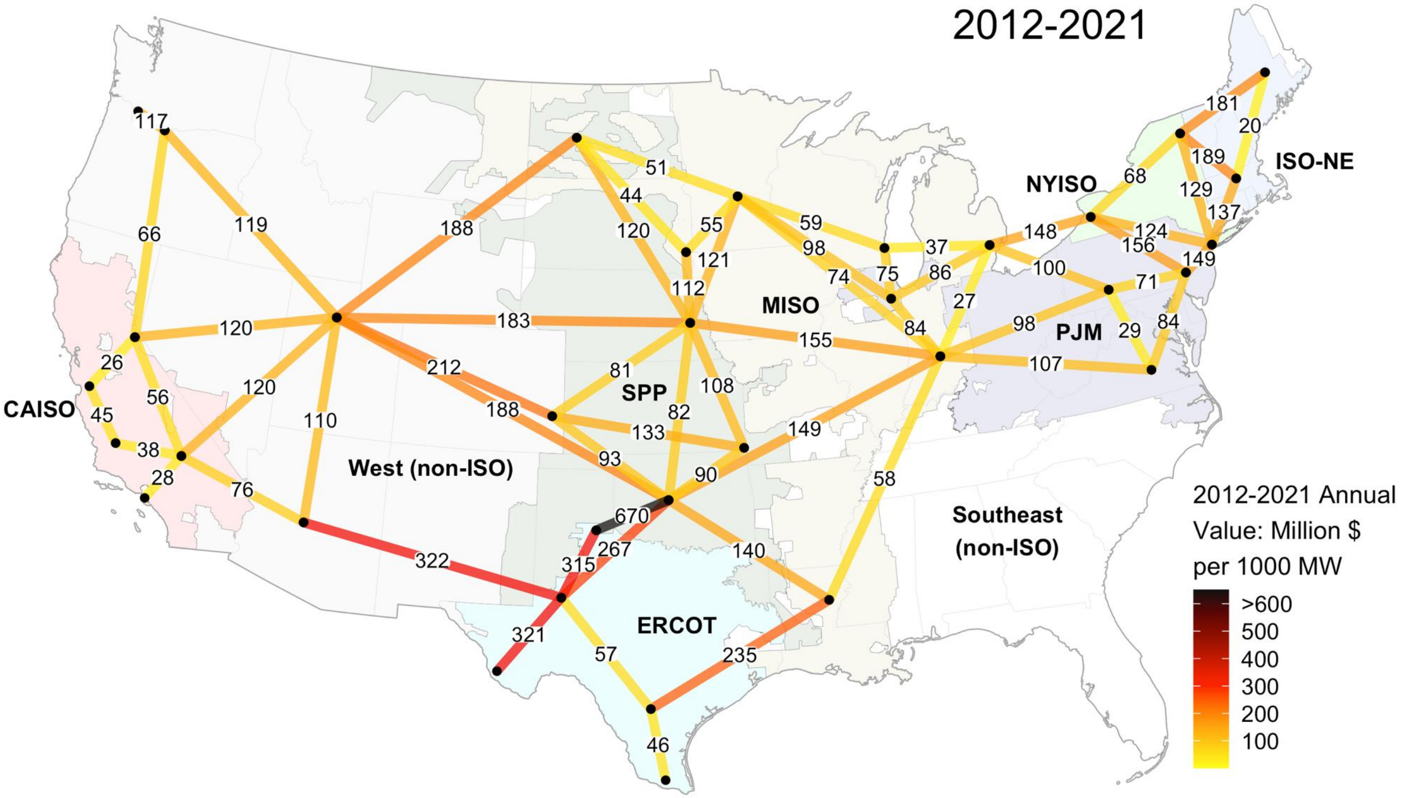
Marginal value of transmission in relieving congestion in 2012-2021 (in $/MWh Units)



$2/MWh to $77/MWh

- Relatively high value links are found in many regions
- High value links to the Texas panhandle and Texas Big Bend region are valuable due to unusually high values found in 2018 and 2019 at these locations
- Extreme events are discussed more generally in the next section

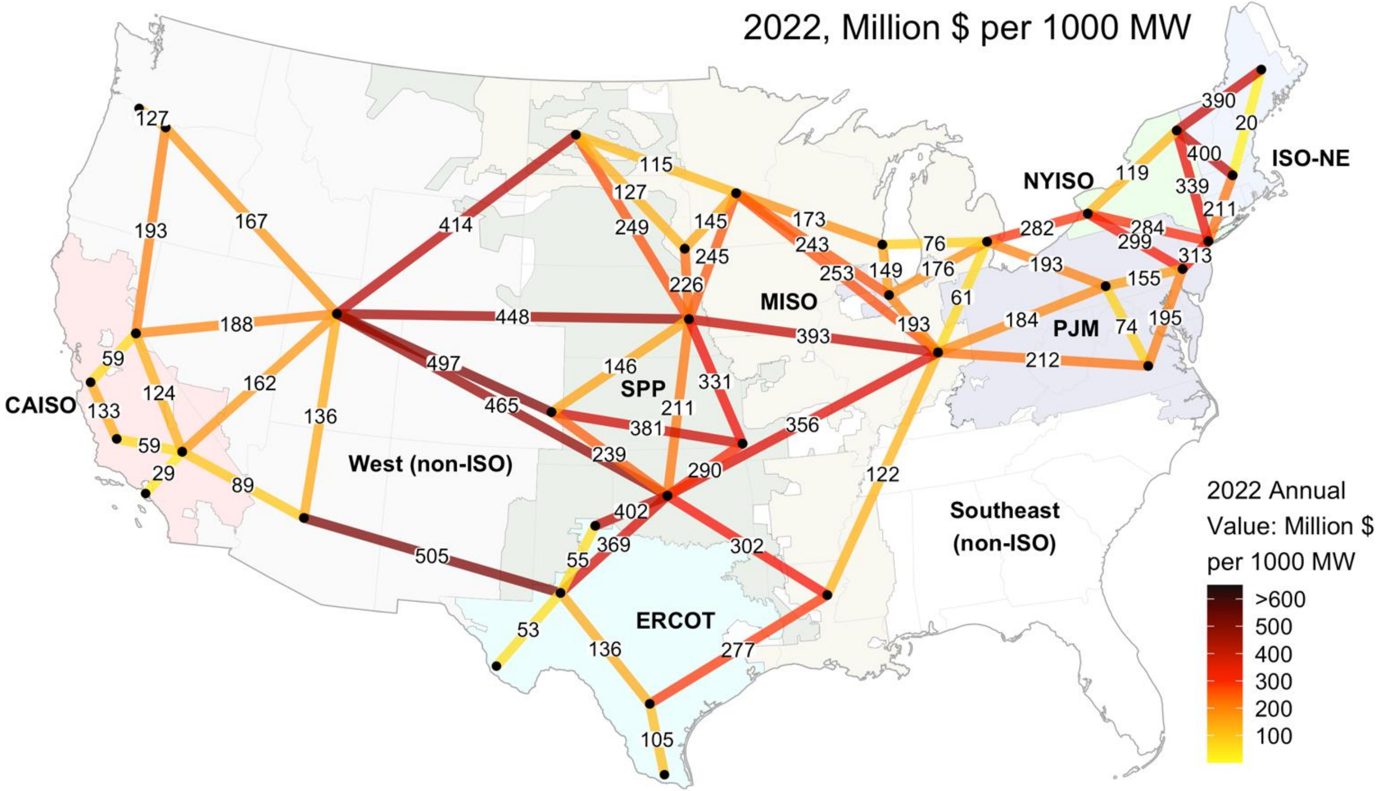
Marginal value of transmission in relieving congestion in 2012-2021 (in $/1000 MW-year units)



$20 to $670 million/year
(for 1000-MW capacity)

- Relatively high value links are found in many regions
- High value links to the Texas panhandle and Texas Big Bend region are valuable due to unusually high values found in 2018 and 2019 at these locations
- Extreme events are discussed more generally in the next section

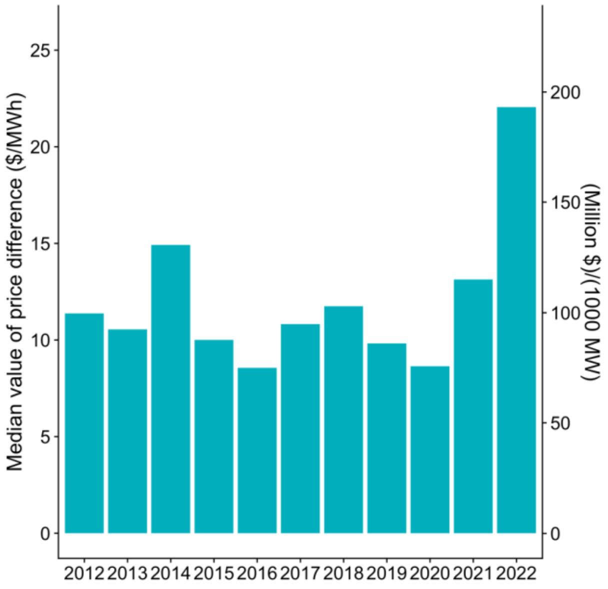
Transmission values high in 2022

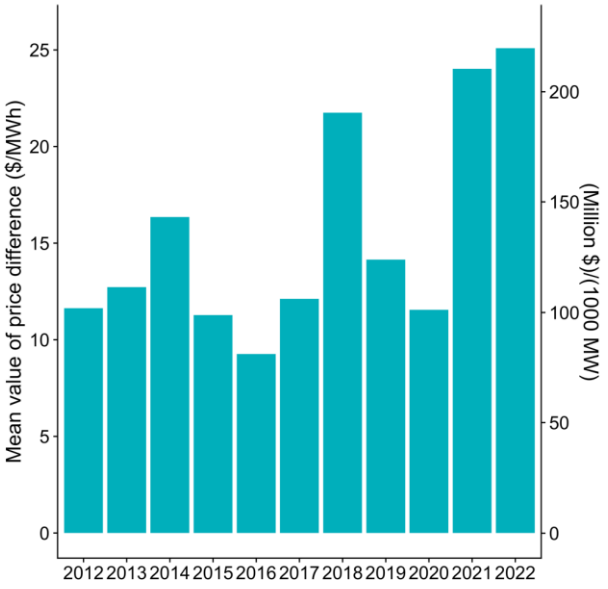


In 2022:

- **$29 to $505 million/year (for 1000-MW capacity)**
- **$3/MWh to $58/MWh**
- A number of interregional links reached $200 to $300 million per 1000 MW (or $23 to $34 per MWh)
- Main drivers: High electricity prices in 2022, extreme weather (winter storm Elliott), plus other factors.

Transmission value in 2022: Highest in the study period (2012 – 2022)





- Both the mean and the median value of links reached new heights in 2022
- The median value in 2022 stands out as a outlier relative to past years, but the mean value in 2022 is similar to values seen in 2021 and 2018
- The high *median* value shows that transmission value increase in 2022 was a broad phenomenon, rather than focused in limited regions as in 2021 and 2018

Analysis of Transmission Value During Extreme Events and High Value Hours

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Identifying extreme conditions: Two approaches

1. Identify a list of specific events that are known to have impact the electricity grid through literature review and NERC reports
2. At each link, find a subset of hours with the highest values (i.e., the top 10%, 5%, and 1% of all hours)

- These approaches identify a somewhat overlapping set of hours, and we take care to prevent double counting where relevant

Designated events

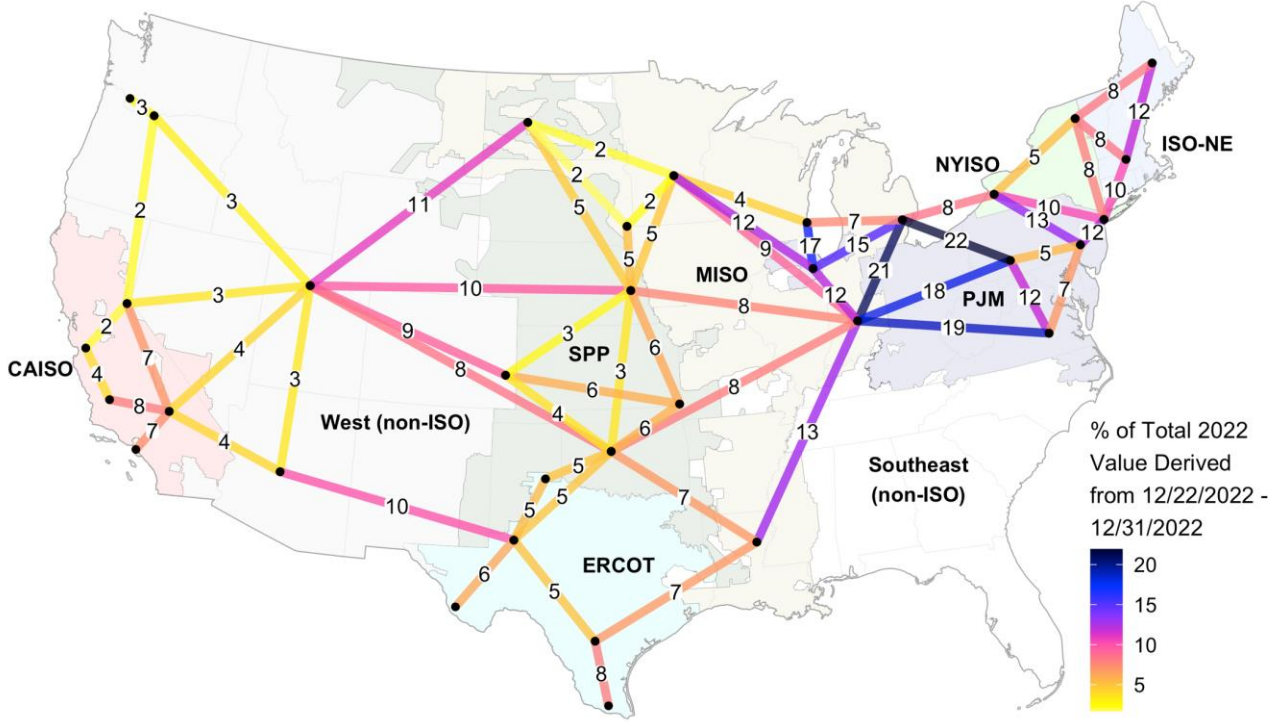
- Weather events identified in the literature: Named storms, heatwaves, polar vortex, etc.
- Periods of 'grid stress' identified in NERC reports

Top X%

- Hours identified by unusually large differences in prices between locations
- Specifically, the top 1%, 5%, 10% of price differences between locations over a specified time period.
- These hours may or may not overlap with the 'designated' events.

NERC: "North American Electric Reliability Corporation"

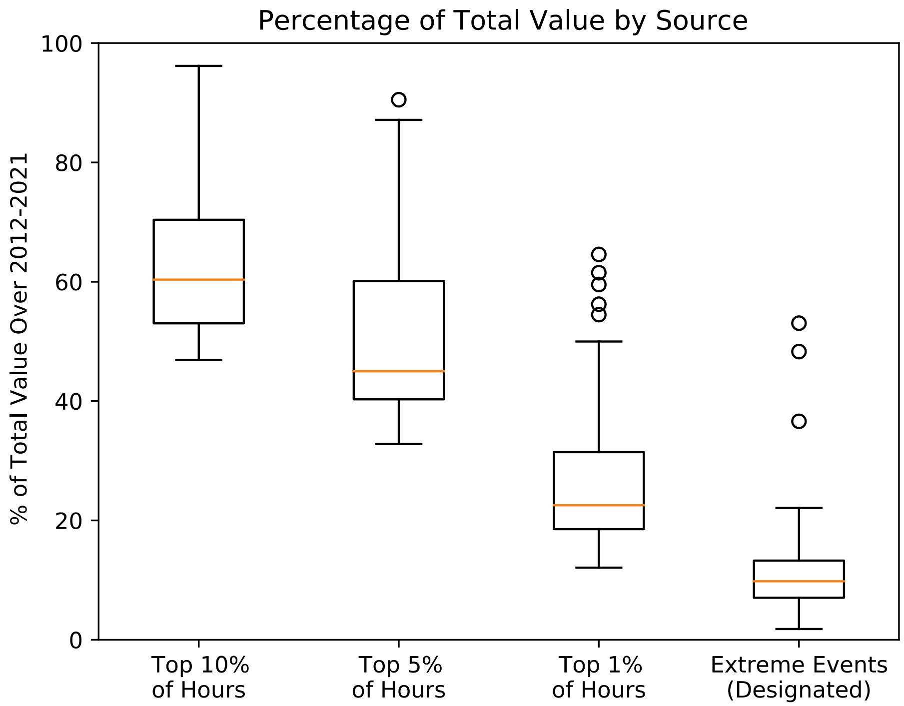
Winter storm Elliott provided a substantial portion of total transmission value in some regions



- Winter storm Elliott accounted for >20% of annual transmission value in a number of links in PJM in 2022
- Winter storm Elliott accounted for ~10% in many other locations
- This value was accrued over just a few days

Extreme conditions and value

- In the median case, the top 10% and 5% of hours accounts for ~60% and ~50% of value, respectively
- The top 1% of hours account of 20 to 30% of total value
- Designated extreme events produce 10% to 20% of value (account for ~5% of total hours)
  - If not designated extreme events, what conditions lead to peak transmission values?

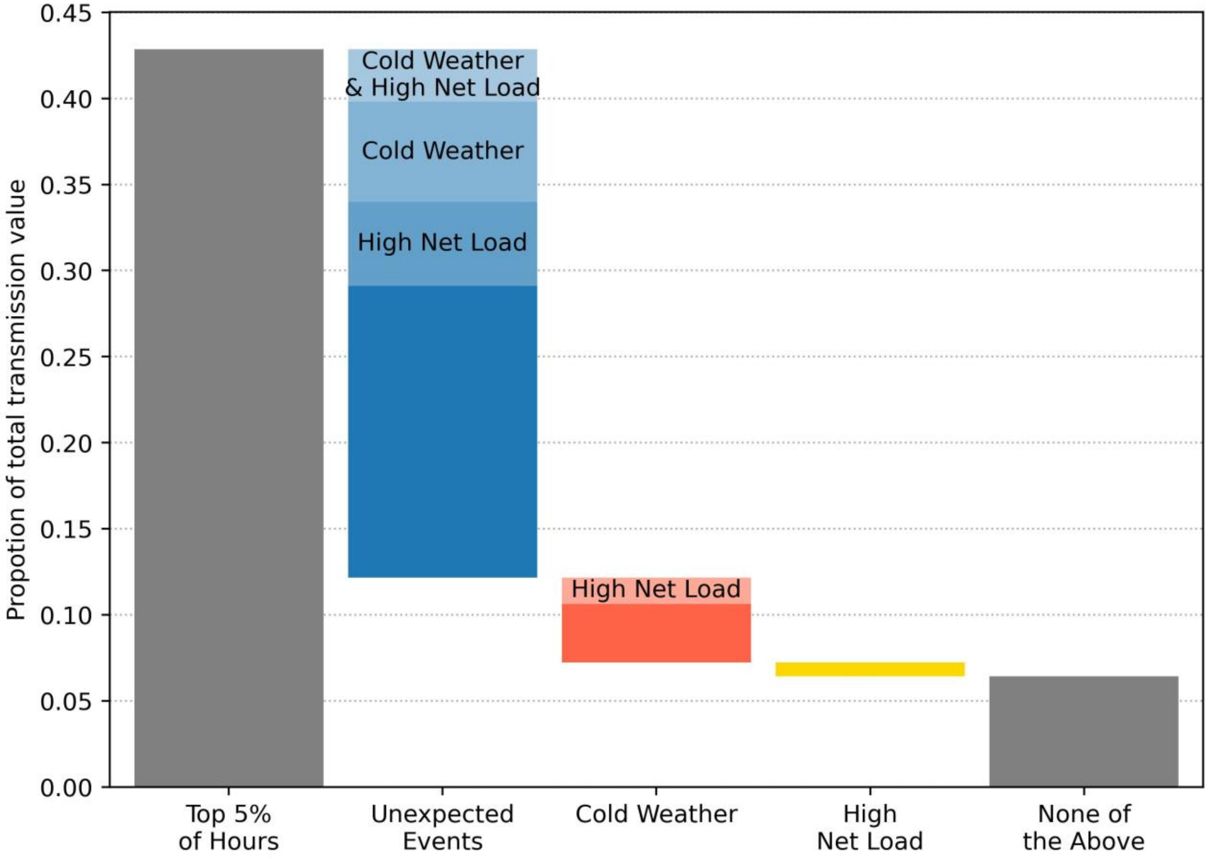


Peak value hours associated with unexpected events, cold weather, and/or high net load

PRELIMINARY

WORK-IN-PROGRESS

- Unexpected events == Large change in nodal price between day ahead and real time markets
  - ≥$40 and ≥50% change
  - Could result from forecast errors, unplanned outages of generators or transmission infrastructure
- What about designated events (e.g., Winter Storm Elliott)?
  - They almost completely overlap with these other conditions
  - <5% of the value in the top 5% of hours is associated with a designated event but none of the other 3 factors



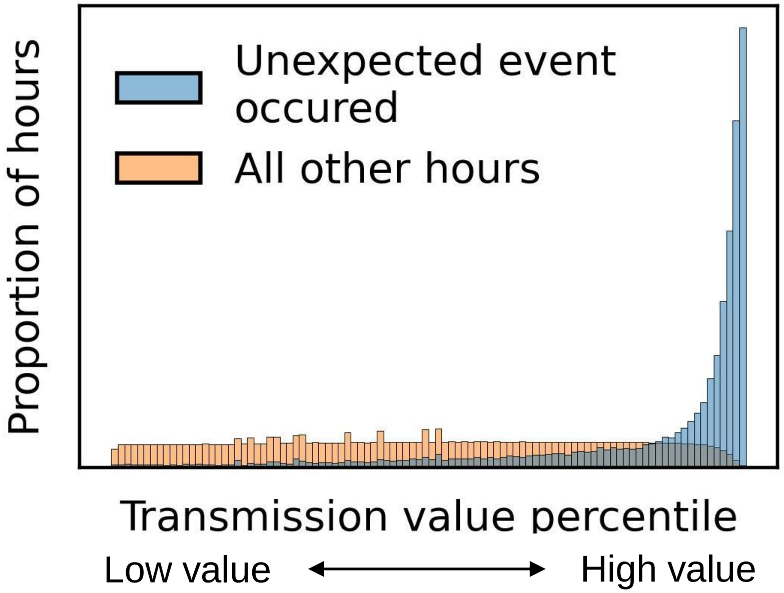
Evidence for causality: These conditions are concentrated during peak value periods

PRELIMINARY

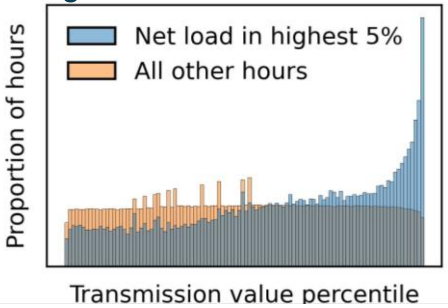
WORK-IN-PROGRESS

- >50% of hours with an unexpected event are in the top 5% of transmission value hours
- High net load and cold weather are also concentrated during high value hours

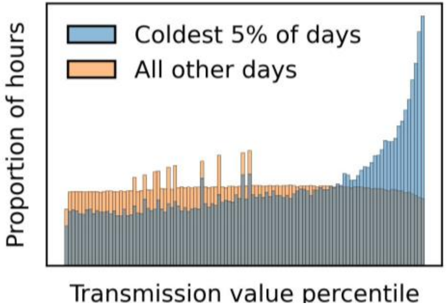
Unexpected Events



High Net Load



Cold Weather



Can models realistically represent the complexity inherent in the values of transmission?

Key challenges to modeling transmission value:

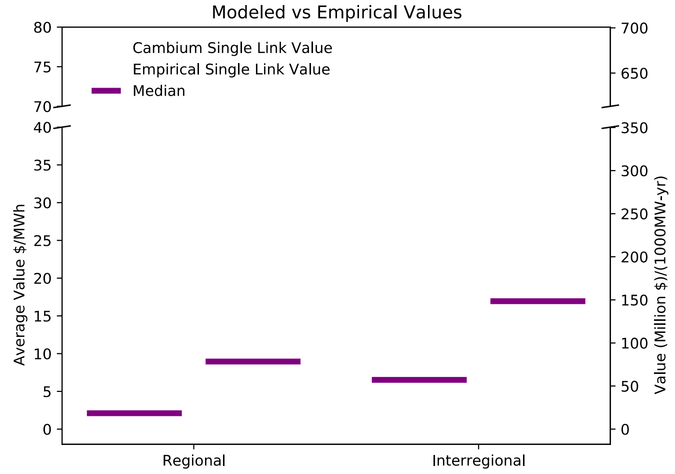
- Lack of a ‘multi-value’ focus and prioritization of only a subset of benefits (i.e., reliability)
- Normalized or average weather profiles
- Limited representation of infrastructure outages and other unexpected events
  - Lack of correlated outages across multiple generators or existing transmission lines
  - Deterministic simulations with limited or no representation of uncertainty in real-time conditions

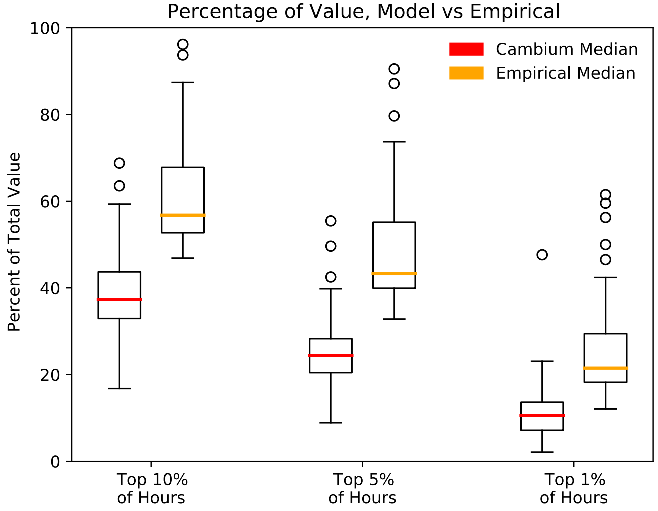
References:

1. Pfeifenberger et al. (2021) “Transmission Planning for the 21st Century: Proven Practices that Increase Value and Reduce Costs” The Brattle Group/Grid Strategies, https://www.brattle.com/insights-events/publications/brattle-economists-identify-transmission-needs-and-discuss-solutions-to-improve-transmission-planning-in-a-new-report-coauthored-with-grid-strategies/
2. Horn et al. (2020) “The Value of Diversifying Uncertain Renewable Generation through the Transmission System” Boston University Institute for Sustainable Energy. https://hdl.handle.net/2144/41451
3. Pfeifenberger et al., (2021) “Initial Report on the New York Power Grid Study” NYSERDA, https://beta.documentcloud.org/documents/20463209-nypowergridstudy

Model example: Value underestimated by ~3X

- Cambium-based national Standard Scenario modeling (*Ref 1*)
  - Note: This model is *not* used in a regulatory context and the modeling system has explicit limitations in representing transmission value, including, but not limited to, a zonal rather than nodal market representation
  - The comparison is based on the average 2012 – 2021 empirical values versus a modeled year of 2022
- This demonstrates the consequences of not explicitly representing extreme conditions, extreme events, fuel-price volatility, generation and load uncertainty, and geographic market resolution in estimating transmission value
- One likely cause for this discrepancy in value is that a much smaller portion of total modeled value is due to extreme events or high value hours compared to the empirical analysis
  - For example, the top 5% of hours account for ~50% of value empirically, but only 25% in the modeled system





1. Cole et al. (2021) "2021 Standard Scenarios Report: A U.S. Electricity Sector Outlook" National Renewable Energy Laboratory (NREL). NREL/TP-6A40-80641. https://www.nrel.gov/docs/fy22osti/80641.pdf

Conclusions

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Key conclusions

1. Regional and interregional transmission links have significant potential economic value
2. The value of transmission is correlated with overall energy prices
3. A small number of high-value hours play an outsized role in the value of transmission – 50% of transmission's congestion value comes from only 5% of hours
4. High value hours are associated with:
   - Unexpected changes to conditions (difference between day ahead and real time)
   - Extreme conditions (e.g., extreme cold or high net load)
5. Transmission planners run the risk of understating the benefits of regional and interregional transmission if unexpected and/or extreme conditions are not adequately considered.

Contact and acknowledgements

Contact: Dev Millstein (dmillstein@lbl.gov)

Full Report: https://emp.lbl.gov/publications/empirical-estimates-transmission

More Information: https://emp.lbl.gov

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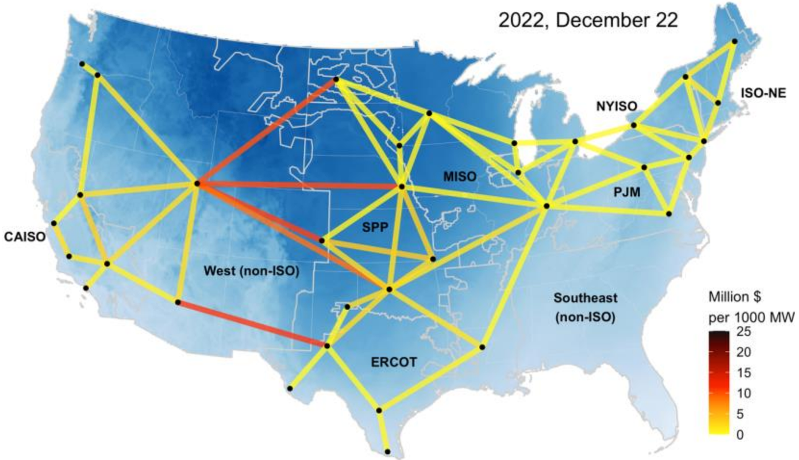
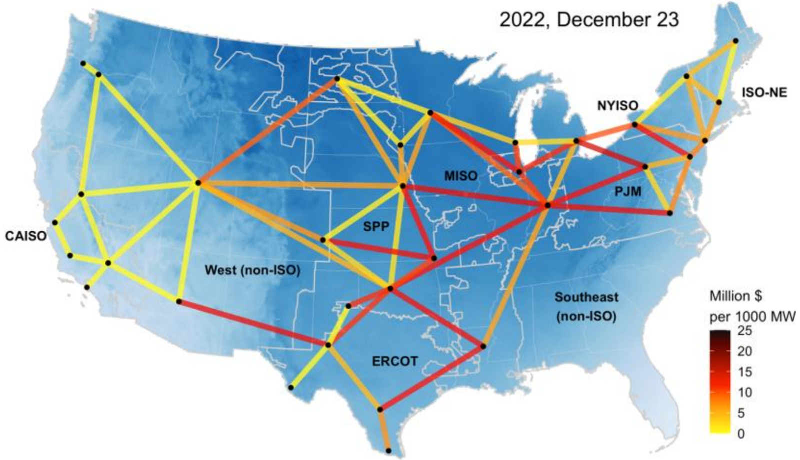
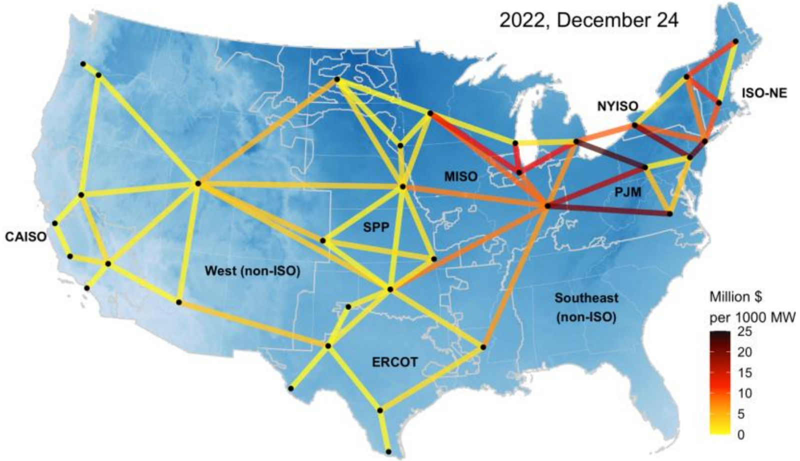
Appendix

Transmission value followed winter Storm Elliott as it moved from west to east





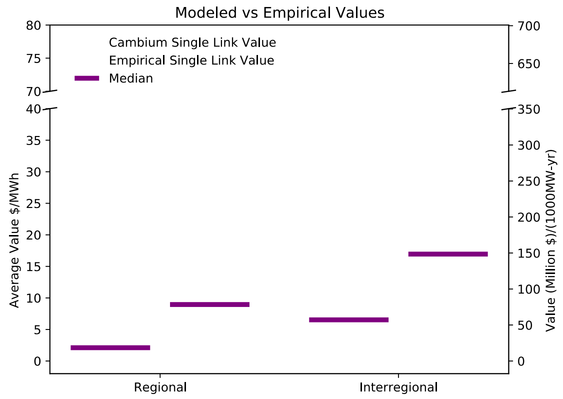
The value shown is calculated as a total for each day (central time). Darker blue colors indicate colder surface temperatures.

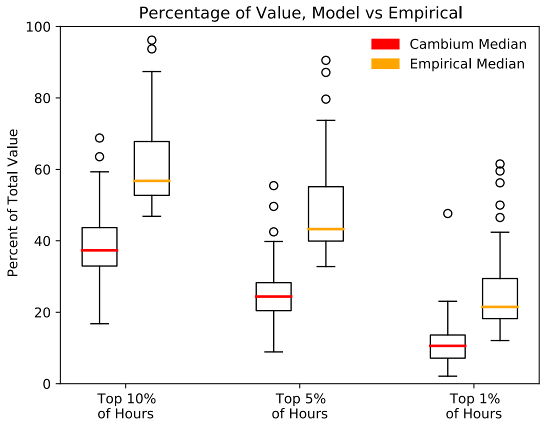


Identifying extreme conditions: Designated events

- We identified 171 extreme event days (with many events covering multiple consecutive days) between 2012 and 2021.
- We identified these extreme events based on specific events listed in:
    1. Goggin M. (2021) “Transmission Makes the Power System Resilient to Extreme Weather”, Grid Strategies. https://acore.org/transmission-makes-the-power-system-resilient-to-extreme-weather/#:~:text=The%20analysis%20finds%20that%20each,Uri%20in%20February%20of%202021
    2. Novacheck et al. (2021) “The Evolving Role of Extreme Weather Events in the US Power System with High Levels of Variable Renewable Energy” National Renewable Energy Lab. (NREL), NREL/TP-6A20-78394. https://doi.org/10.2172/1837959
- We also identified the top-10 NERC high grid stress days (using the severity risk index) as designated by NERC in their Annual State of Reliability reports. These can be found at https://www.nerc.com/pa/RAPA/PA/Pages/default.aspx
- These events covered various weather events, such as heatwaves, cold snaps, hurricanes, polar vortices, bomb cyclones, wind storms, winter storms, and other extreme weather events.
- The events also included non-weather related stressors, such as coincidental generator outages.

Methods for the comparison to modeled transmission value





- Here we examined the NREL Standard Scenarios which were created with a combination of the capacity-expansion model ReEDS and the dispatch model Plexos.
- We examined value in the model year 2022, using the 2021 model version, and specifically used the 'mid-case' scenario. See https://scenarioviewer.nrel.gov for more information.
- We matched model balancing areas to the empirical nodes and compared price time series between balancing areas to determine value in a similar manner to how value was determined in the empirical analysis. 9 of 64 links were not able to be recreated as both ends were contained within a single modeled BA. Of those 9, 4 were located in CAISO, 2 in NYISO, 2 in PJM, and one in ERCOT. All interregion links were replicated.
- We compared value to the average empirical value across 2012 – 2021. Empirical values were on average larger in 2021 and the beginning of 2022, meaning that the comparison to only recent data would show a larger discrepancy between modeled and empirical transmission value.
- Modeled average wholesale prices were similar to average empirical prices over the 2012 – 2021 period, though modeled prices were overall ~10% lower than observed prices. This difference in overall wholesale prices likely accounts for a small portion of the difference in modeled to empirical value of transmission. It would not account for the difference in the portion of transmission value contained in the top 5% of hours.