Improving estimates of transmission capital costs for utility-scale wind and solar projects to inform renewable energy policy

Please Note:
- All participants will be muted during the webinar
- Please submit questions via the chat window
- This webinar will be recorded

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Electricity Markets and Policy Group Webinar

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Outline of the presentation

Part I: Motivation and Introduction

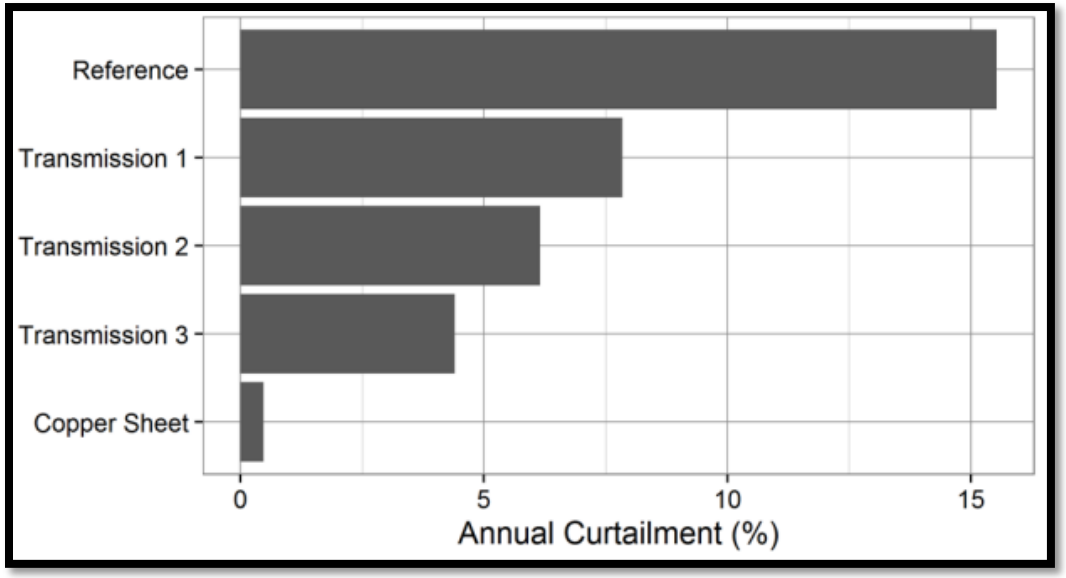
Part II: Estimation Methods

Part III: Results

Part IV: Conclusion

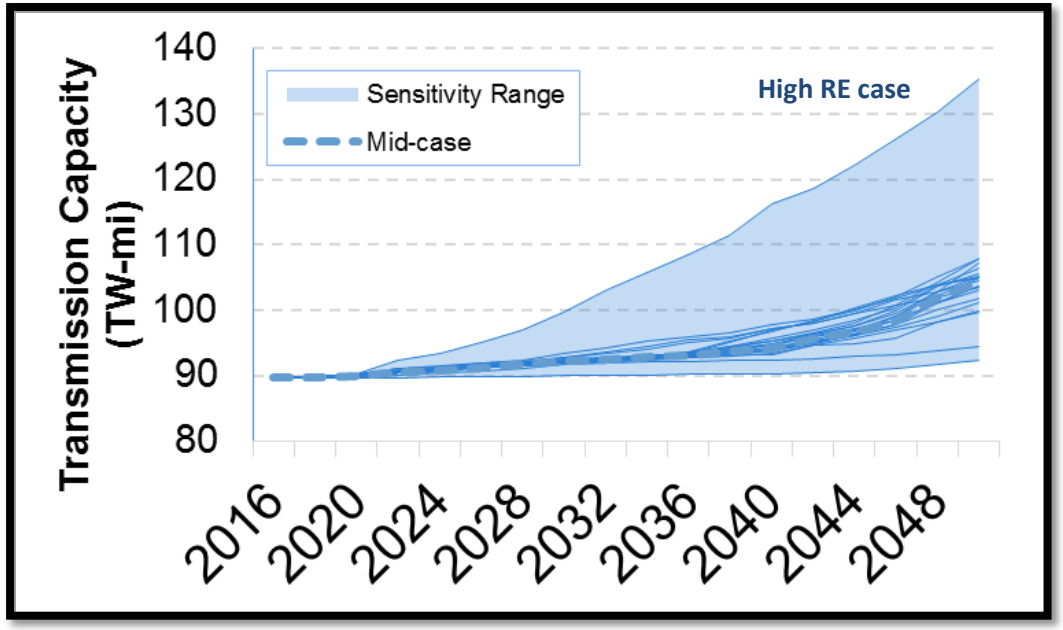
Future expansion of renewables will require more transmission investment

Reducing wind curtailment through transmission expansion



Source: NREL 2017

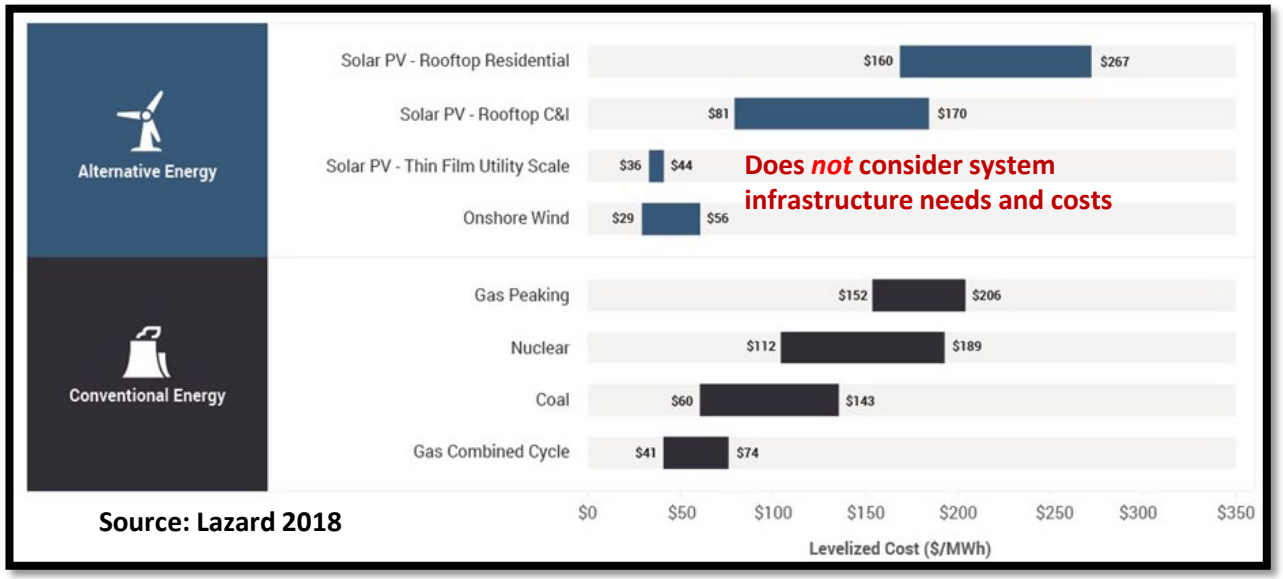
Projected Transmission needs



Source: NREL Standards Scenarios

Popular cost metrics like LCOE do not typically include system costs

Lazard levelized cost of electricity generation 2018



Source: Lazard 2018

However, estimating the **overall costs of transmission** to integrate variable renewable energy (VRE) onto the grid is challenging.

Pertinent Questions

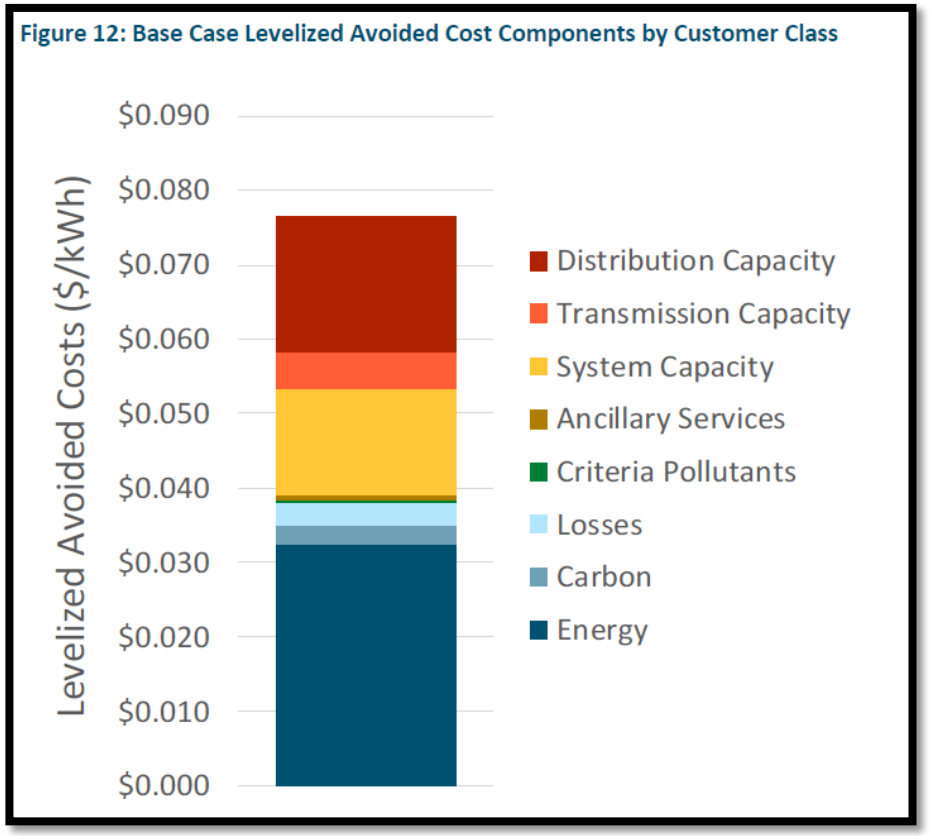
(1) **How have VREs** benefitted from transmission expansion in the past?

(2) What might **transmission investments** for VREs be in the future?

(3) Can **electric system planners** facilitate optimal transmission construction?

Debate over a distributed vs. utility-scale future

- Many studies trying to understand the **value of DERs** on the grid
- **One component** of value is transmission deferral or avoidance
- E3 calculates **~$3-5/MWh** of levelized benefit



Source: E3 2016 study for Nevada Legislative Committee on Energy

Transmission cost estimates from previous work

- **Review of U.S. transmission planning studies:** median wind transmission costs of $15/MWh or $300/kW, roughly 15%–20% of a wind project's cost at the time
- **European review of VRE transmission cost**: $7.5–$30/MWh at 30% VRE penetration
- **MISO interconnection review:** wind-related transmission costs of $0.4-$9.7/MWh or $33–$762/kW

Preview of our findings: Similar $/kW with lower $/MWh estimates

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We assess transmission costs by relying on multiple sources

Four approaches:

Attribute	1. Interconnection Studies	2. Simulation Studies	3. Aggregation Method	4. Actual Transmission Projects
Geography considered	MISO, PJM, and EIA	Select regions within U.S.	Entire U.S.	
Cost Responsibility	Developer	Developer (spur lines) and socialized (bulk)		Socialized
Project scopes	Generation project	Transmission system		Transmission project
Costs considered	Actual/study costs (POI and bulk system)	Modeled costs (bulk system and spur)	Actual costs (bulk system)	
VRE amount	Individual projects	Both low and high penetrations		
Generation types	All types	Utility-scale wind and solar only		
Key challenges	Limited bulk costs	Unrealistic optimizations	Coarse analysis Ambiguous cost responsibility	Selection bias Ambiguous cost responsibility

Levelization methods

- **Project Specific Approach:**
  Annualize capital costs (eq. 1)
- **Aggregation Approach:**
  calculate net present value of spending and renewable generation (eq. 2)
- Discount rate = 4.4%
  - Based on real interest rates in utility industry
  - Sensitivity with social discount rate of 2%
  - Lifetime of 60 years

$$LCOT = \left[\frac{C*r}{[1-(1+r)^{-n}]}\right] \div [K * CF * 8760] \qquad \text{Eq. 1}$$

Where
C = capital cost of transmission investment
r = discount rate
n = transmission asset lifetime (in years)
K = incremental capacity (in MW) of VRE integrated by transmission infrastructure
CF = capacity factor of VRE resource

$$LCOT = \frac{\sum_{n=0}^{N} \frac{C_n}{(1+r)^n}}{\sum_{n=1}^{N} \frac{q_n}{(1+r)^n}} \qquad \text{Eq. 2}$$

Where
C = real expenditures in period n
r = discount rate
N = total discount period (in years)
q = renewable energy output (in MWh) in period n

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- Approach I: Interconnection Studies
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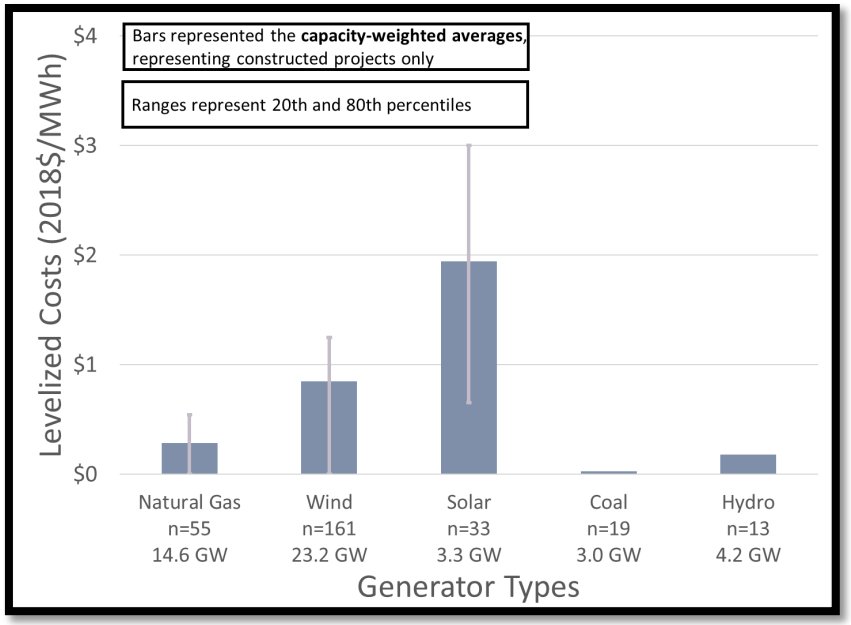
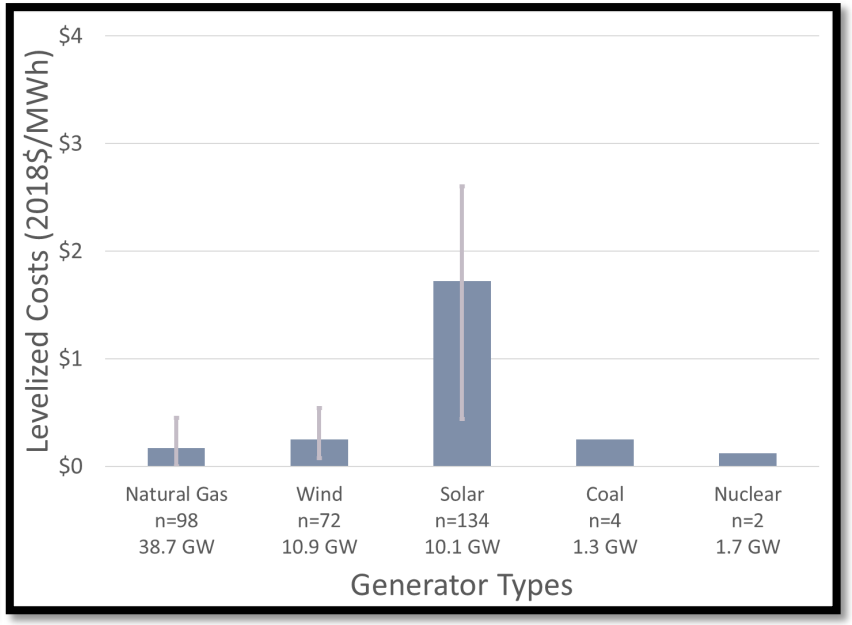
Interconnection costs for VRE slightly higher than for conventional generators

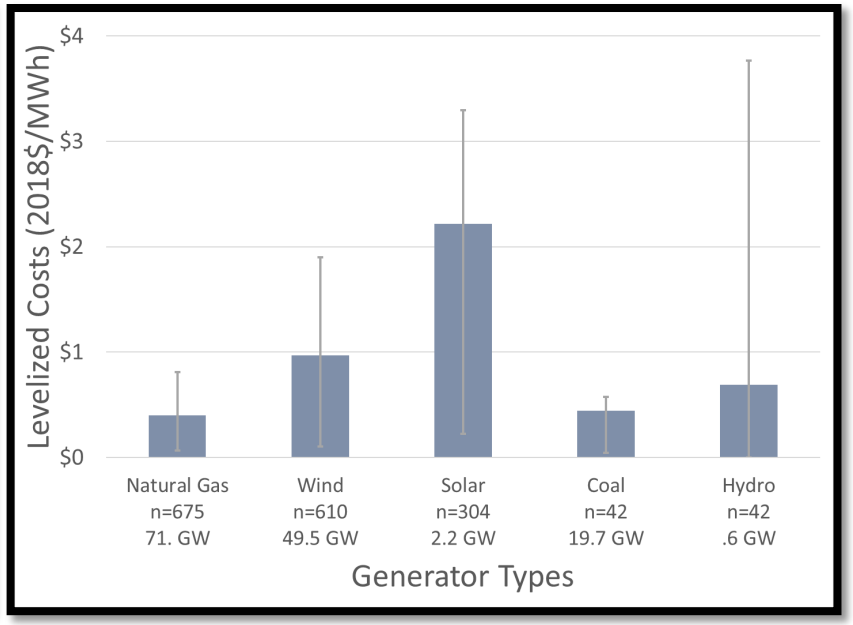
MISO



PJM



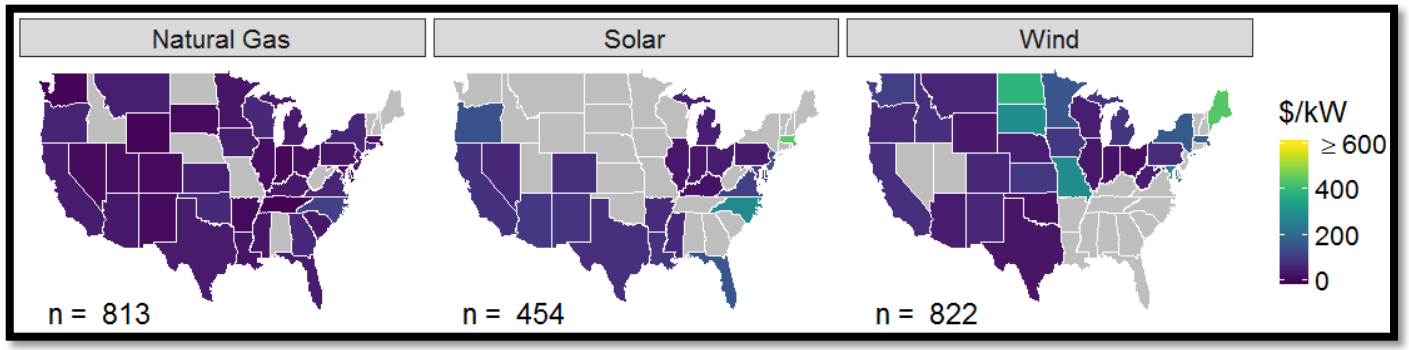
EIA



- Solar has consistently higher **levelized cost** of transmission for interconnection across all sources
- Interconnection costs are **low** compared to total LCOEs for generation technologies

Interconnection costs for wind more expensive in remote areas, with future costs *potentially* higher

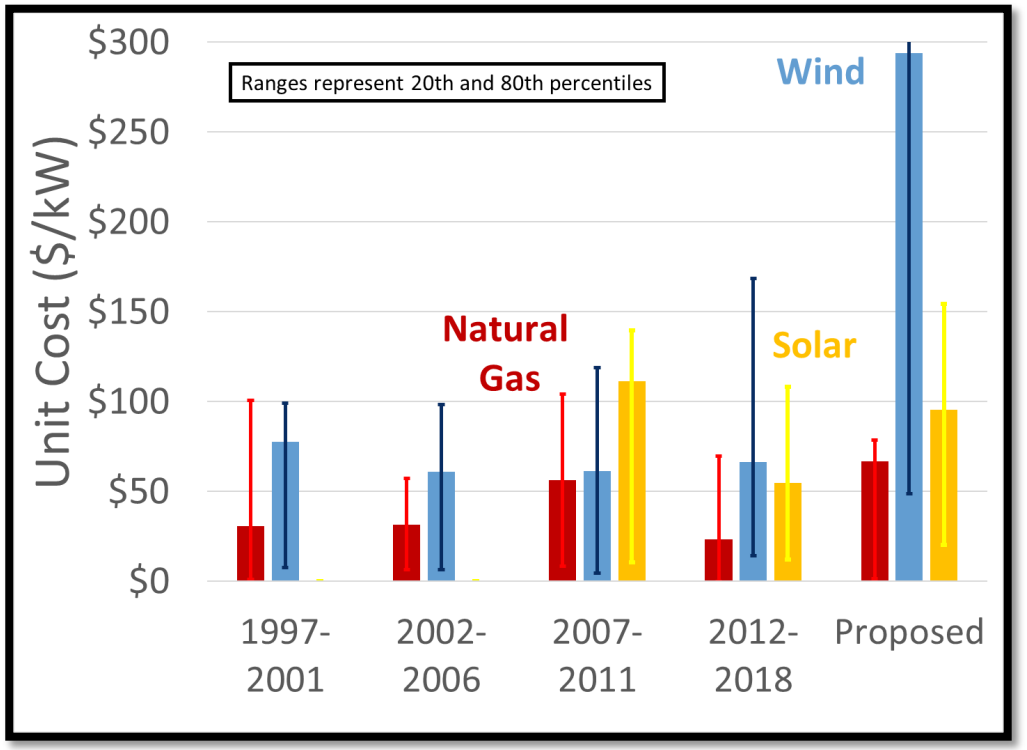
Unit cost by state and generator type



Notes: Combines MISO, PJM, and EIA data

- **Limited geographic heterogeneity** of unit costs to interconnect
- Proposed projects with high costs may not move forward with interconnection

Unit cost by queue entry year



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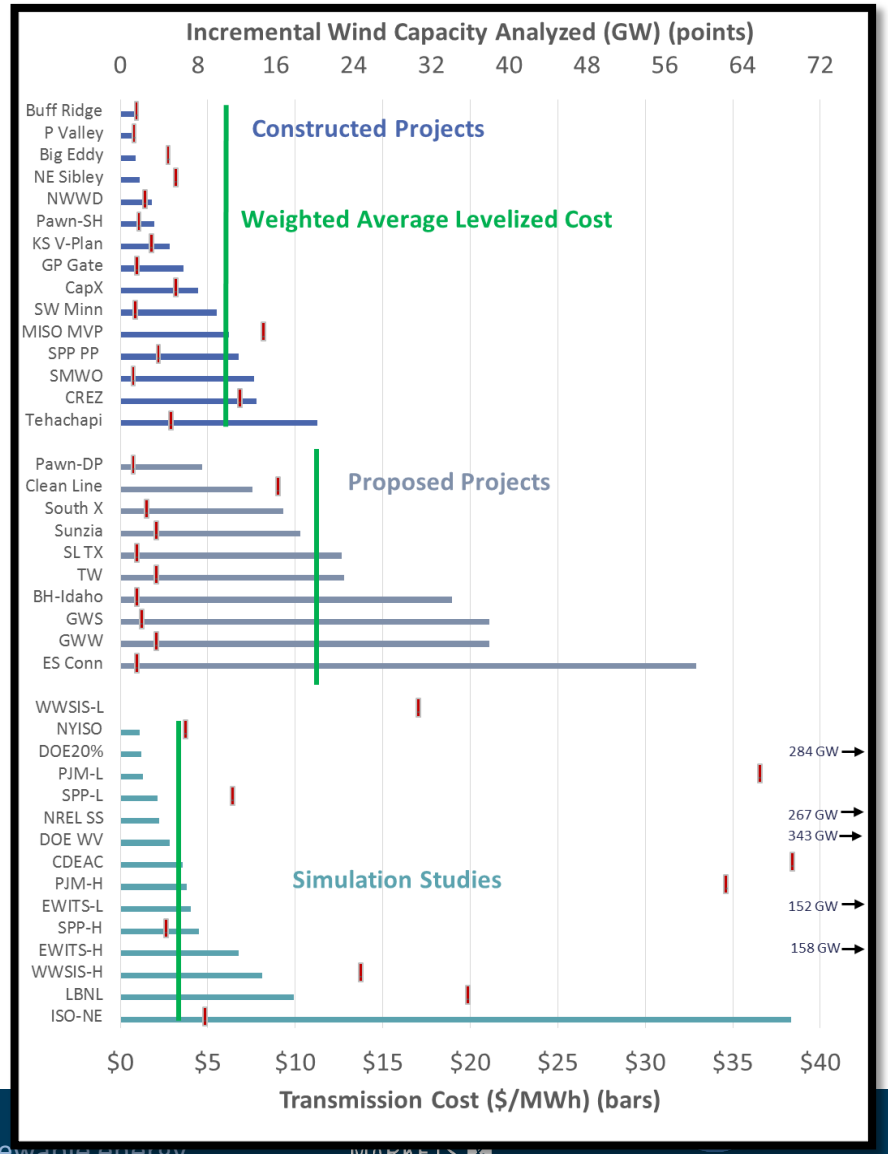
Actual projects were more expensive than simulation studies suggest

- Proposed projects **most expensive**, followed by completed projects and simulation studies
- Challenging to assign **cost responsibility** appropriately



Same story for solar, though much less data

- Only four transmission projects with enough **certainty** to report
- In 2010, **40 GW** of utility-scale wind to **1 GW** of utility-scale solar.
- By 2017, ratio grew to **88 GW to 25 GW**

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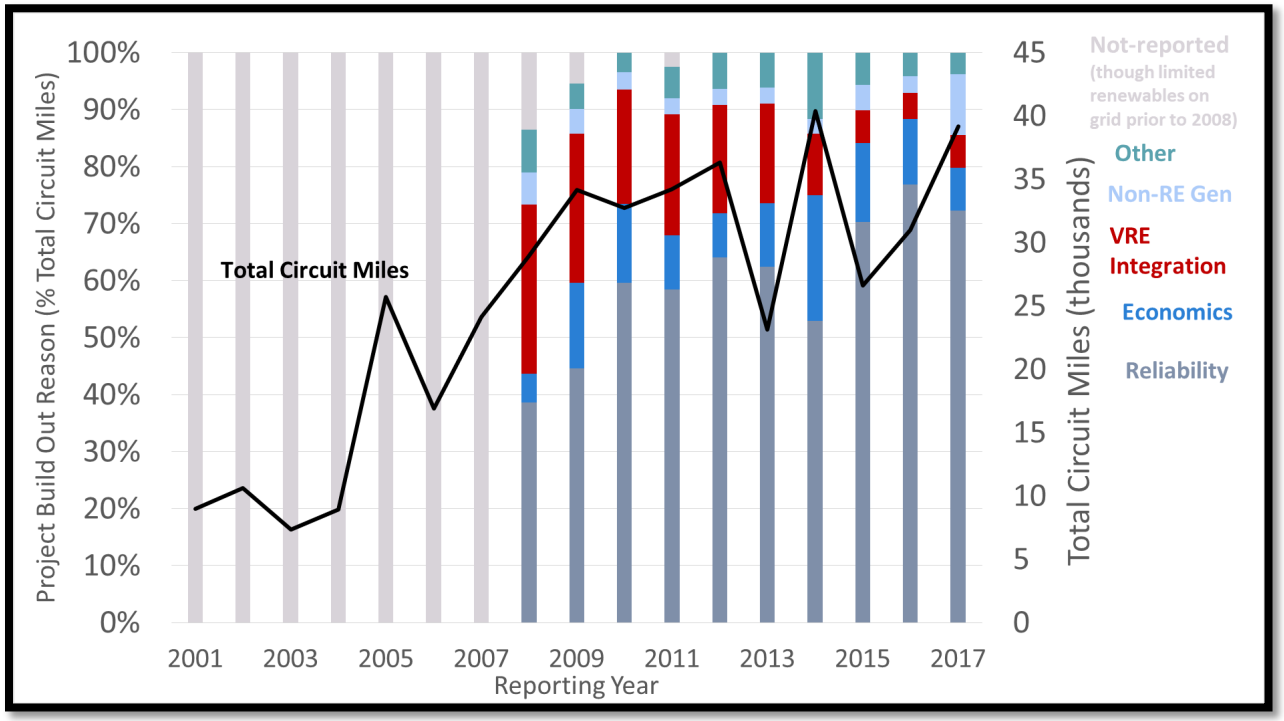
Combine data from EEI, EIA, and NERC

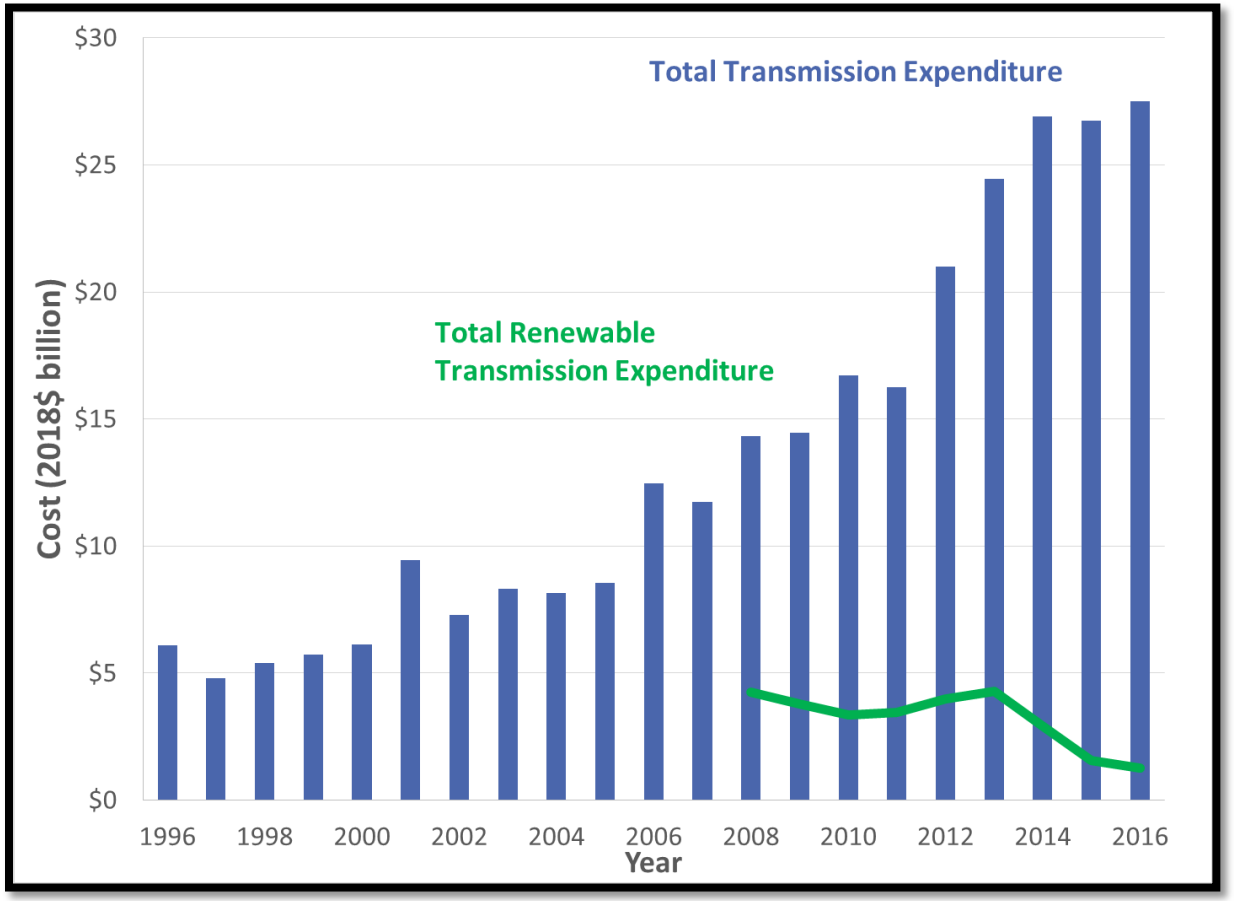
- **Step 1:** collect region-wide time series of VRE transmission expenditures and calculate net present value
- **Step 2:** collect region-wide VRE generation
- **Step 3:** divide step 1 result by step 2 to calculate levelized cost of transmission



Source: EIA Form 411

Aggregation results form midpoint estimate

- U.S. wide: **$7/MWh**
  - Solar and wind
  - EIA compiles **reason** for transmission expansion
  - FERC form 1 compiles historic transmission expenditure
- ERCOT: **$7.8 – 4.1/MWh**
  - Wind only
  - Variation driven by how you count amount of **wind integration** due to **CREZ**



Source: FERC form 1 and EIA form 411

California aggregation leads to similar results

- U.S. wide: **$8.3/MWh**
  - Sunrise Powerlink and Tehachapi lines account for **almost 75%** of expenditures.
  - Should we include **outside CA** renewable resources which **might** have relied on these transmission expenditures?

Transmission Project	California ISO Status	In-Service Date	RPS target	Cost Source	Cost Million ($2018)
Sunrise Powerlink 500 kV line	Approved	2012	33%	Sempra	$2,023
Sycamore Canyon-Peñasquitos 230 kV Line	Approved Policy with Reliability Benefits	2018	33%	CPUC	$271
Tehachapi 500 kV line	Approved	2016	33%	EEI	$3,270
Colorado River-Valley 500 kV line	Approved	2013	33%	EEI	$852
Eldorado-Ivanpah 230 kV line	LGIA	2013	33%	EEI	$373
South of Contra Costa 230 kV Reconductoring	LGIA	2012	33%	Estimated	$50
Carrizo-Midway 230 kV Reconductoring	LGIA	2013	33%	Estimated	$53
Path 42 230 kV Reconductoring	Approved Policy	2016	33%	EEI	$32
IID: Path 42 230 kV Reconductoring and additional upgrades	N/A	N/A	33%	LBNL	$41
LADWP: Barren Ridge 230 kV line	N/A	2016	33%	LADWP	$312

Source: Various (EEI, CPUC records)

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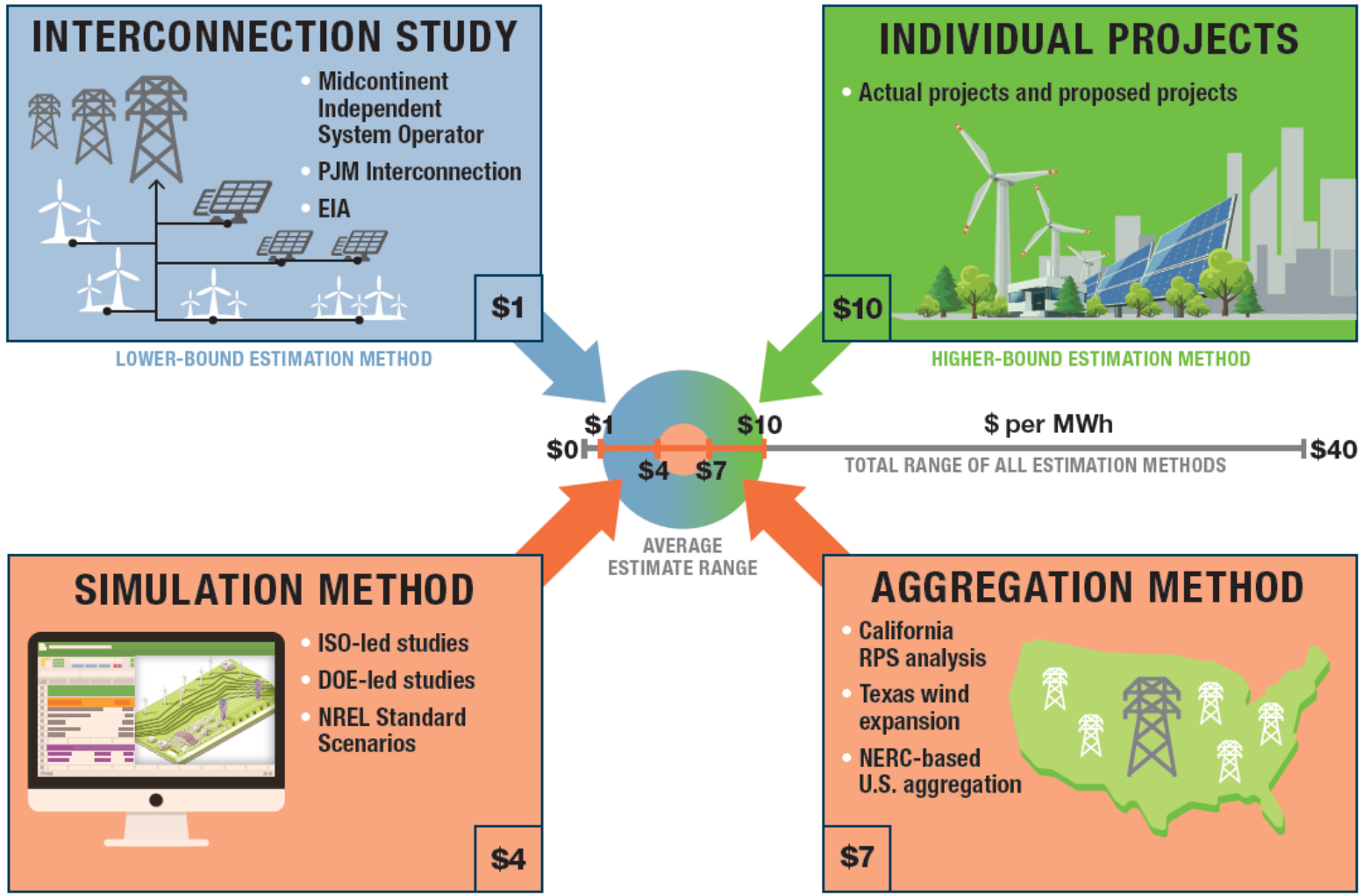
Transmission costs range from $1-$10/MWh



- Considerations:
  - Compare to wind (**$29-56/MWh**) and solar LCOE **($36-46/MWh)**
  - Difficult to assign **cost responsibility**
  - Simulation projects represent **idealized** optimization
  - Bulk vs. interconnection investments
  - We only consider **capital costs** (ignore O&M costs)

Conclusions

- Future renewable expansion will require **transmission investment**
  - Needed to reach renewable energy policy targets
  - Needed to reduce renewable curtailment

- ***Average*** transmission ***capital*** costs range from $1-$10/MWh
  - Does not include O&M expenses → Future work
  - Does not consider full cost-benefit analysis → Future work

- System planners need to **consider transmission needs today** to meet renewable expansion priorities in the future
  - This work informs distributed vs. utility-scale debate while contextualizing system-level integration costs

Questions?

- Contact the presenters
  - Will Gorman and Andrew Mills
  - WGorman@lbl.gov
  - ADMills@lbl.gov
- Project team at Lawrence Berkeley National Laboratory:
  - Will Gorman
  - Andrew Mills
  - Ryan Wiser

Download all of our work at:

http://emp.lbl.gov/reports/re

Follow the Electricity Markets & Policy Group on Twitter:

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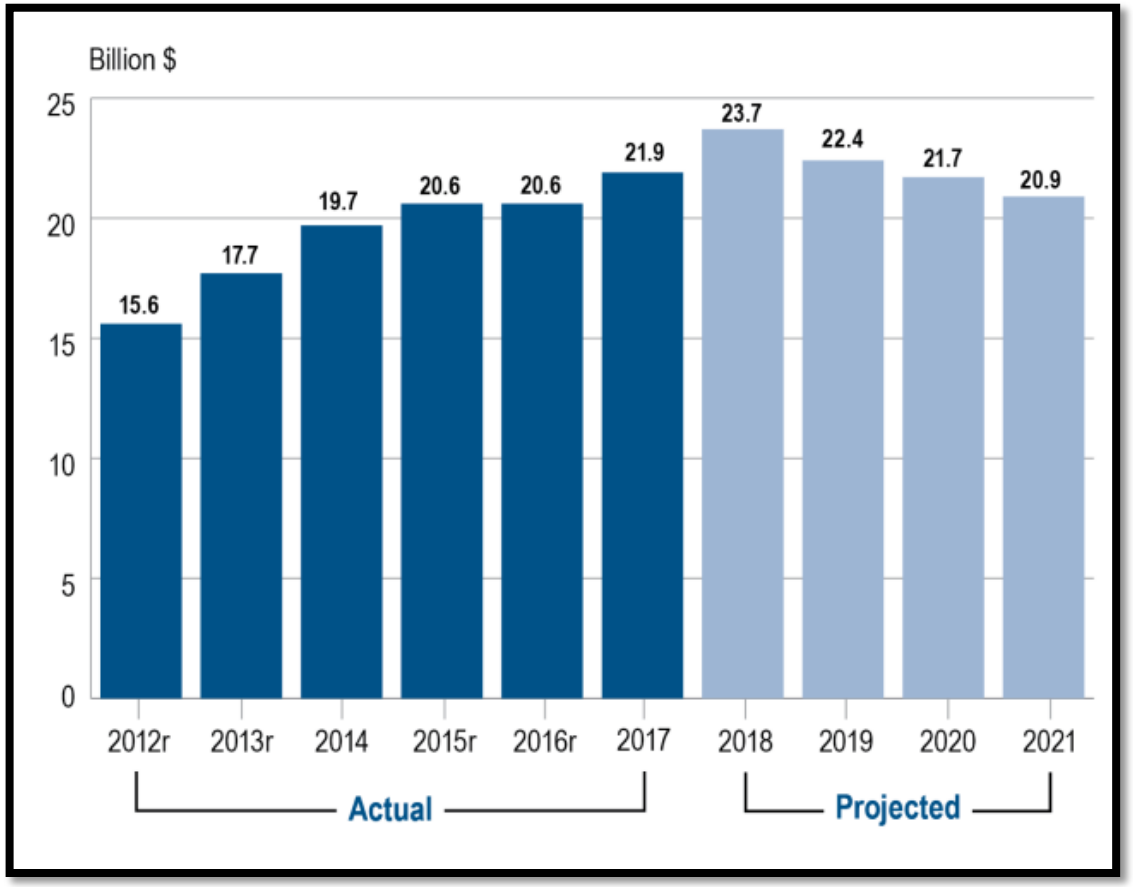
Supplemental Slides

Transmission investment growth (EEI)



Source: EEI Transmission Projects at a Glance

Transmission includes three sub-categories

(1) Bulk transmission

- Networked infrastructure that move power from all generators to all load centers

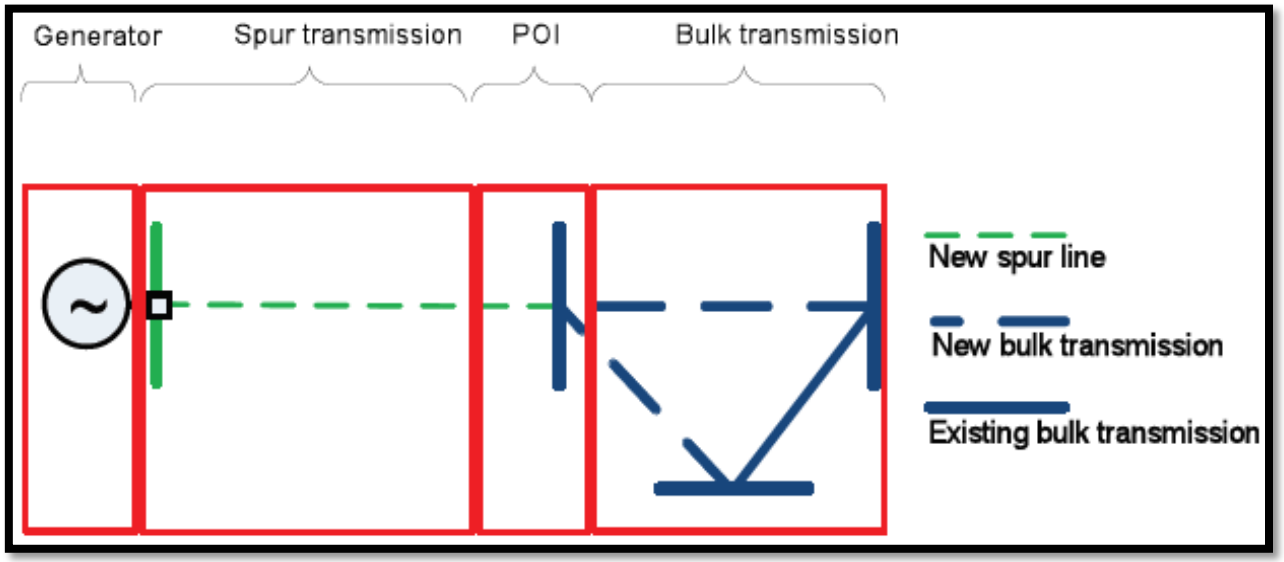
(2) Spur transmission

- Short, radial transmission lines to connect generators to bulk grid

(3) Point of interconnection

- The facilities that connect spur lines to bulk lines

Portions of transmission system



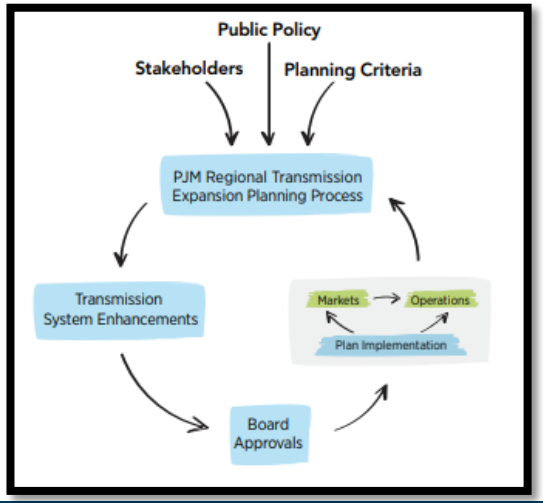
Source: Andrade and Baldick (2017)

Transmission expansion has many drivers

- Transmission network expanded via **three main channels**:
  - **(1)** regional transmission planning
  - **(2)** generation interconnection
  - **(3)** merchant transmission developers

- **Many goals:**
  - reliability
  - economic congestion relief
  - public policy

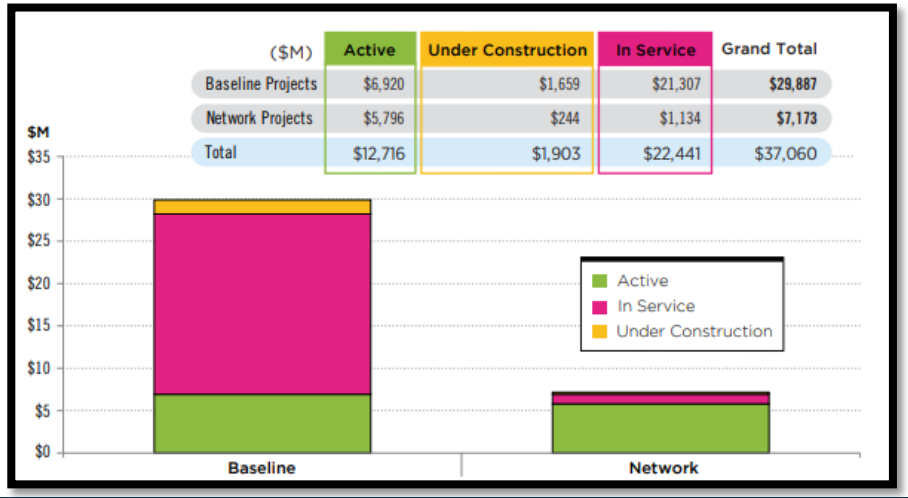
Planning process



Enhancement drivers

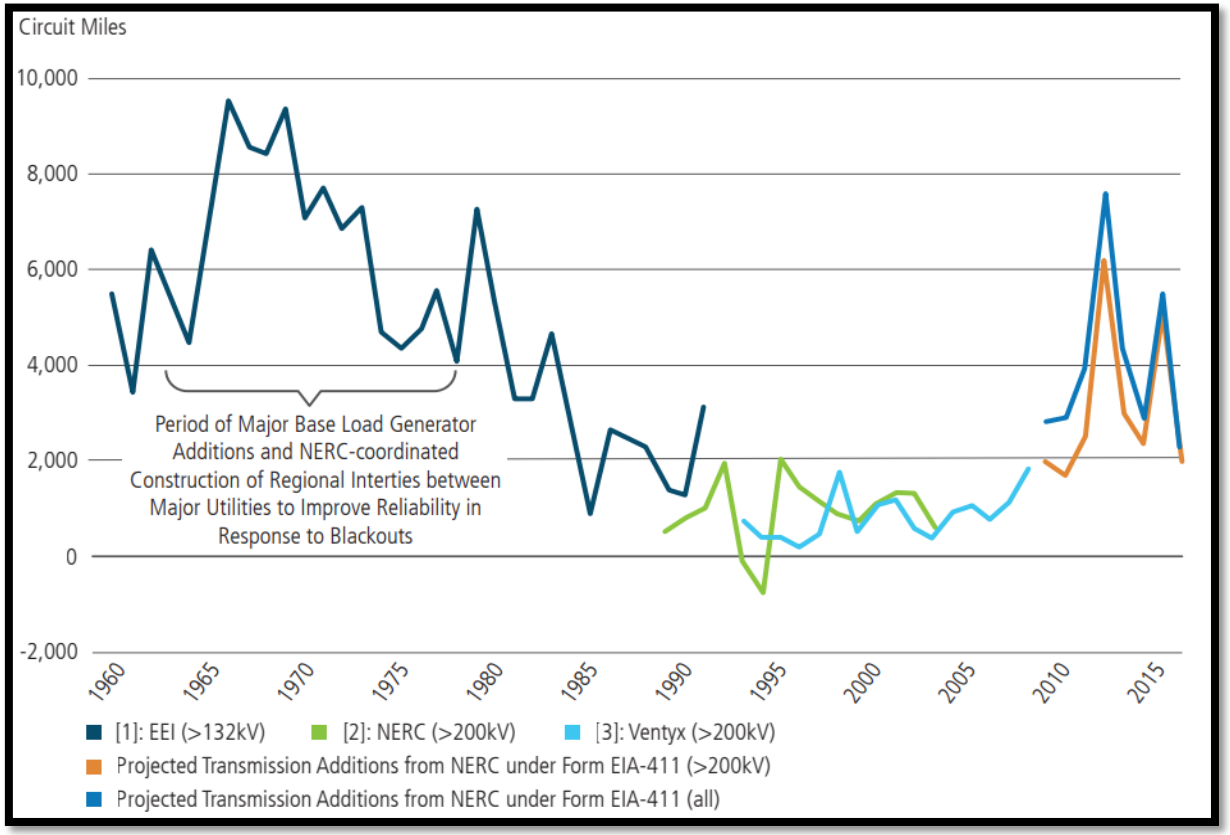
Source: PJM 2018 region transmission plan

PJM Total Historical Approved projects ($37 billion)



Transmission is not just needed for renewables

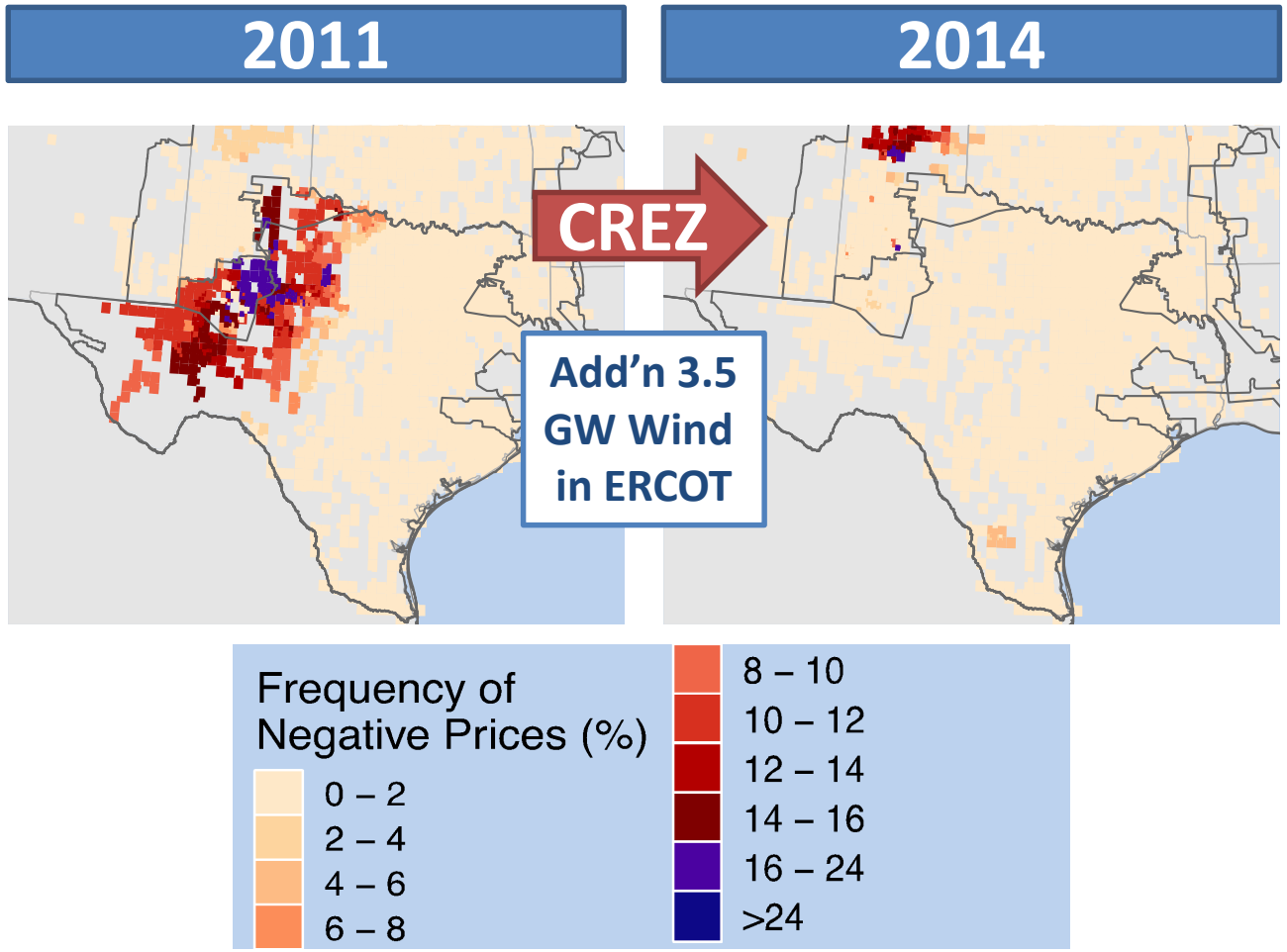
- Historical transmission buildout peaked **in the 1960s and 70s**
- Large transmission expenditures were needed to **integrate conventional generation**

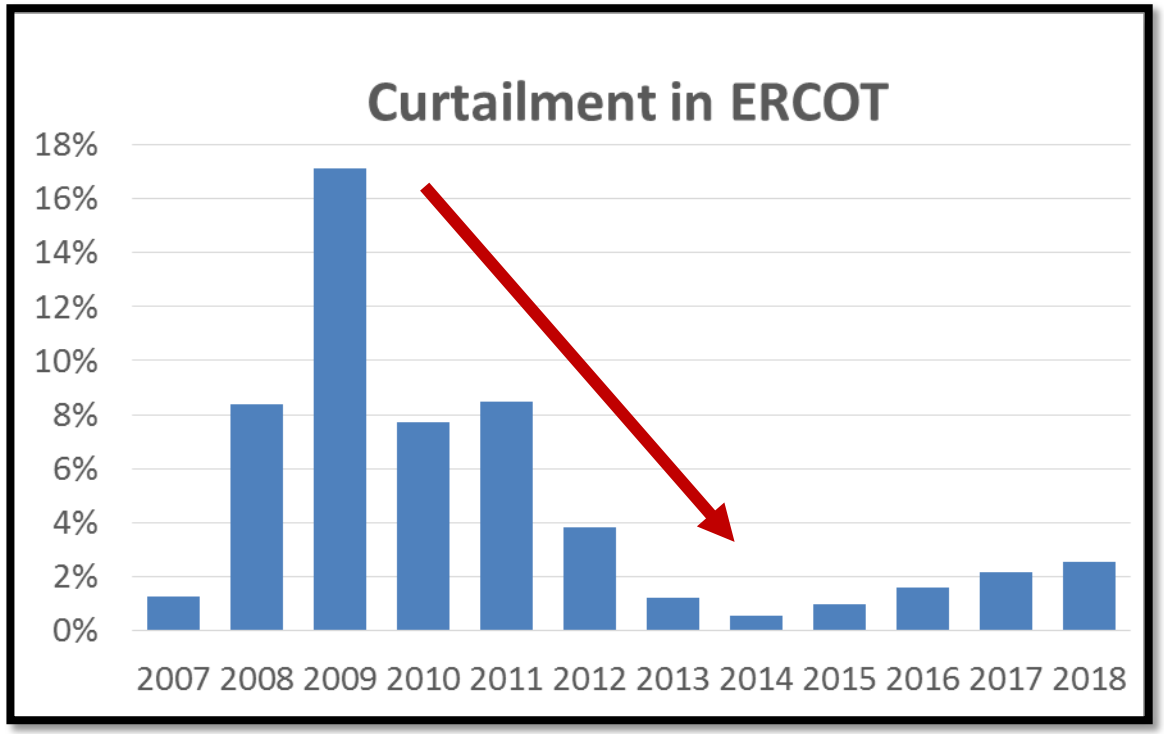


Source: DOE QER: Energy Transmission, Storage, and Distribution Infrastructure (2015)

Widespread negative pricing need not always be permanent: transmission matters

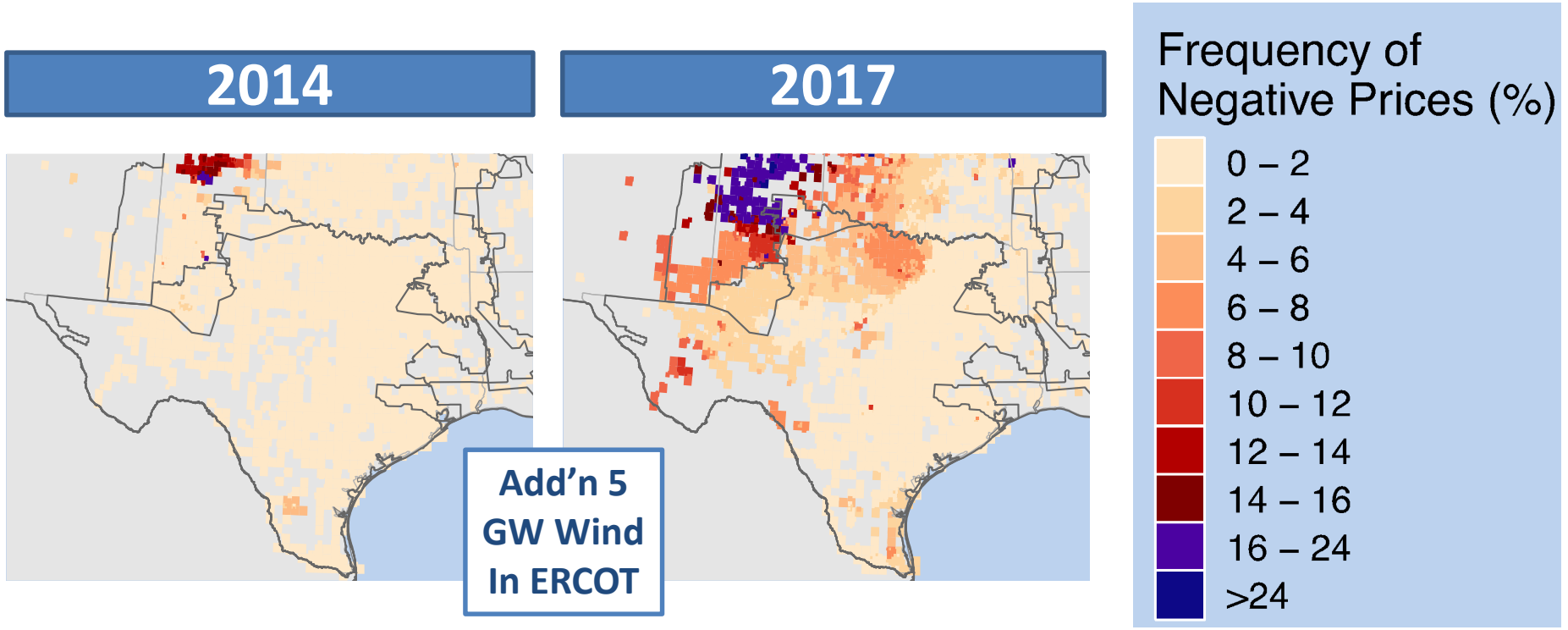
Maps show **reduction** in negative pricing ***after*** the construction of the CREZ lines





Widespread negative pricing need not always be permanent: transmission matters

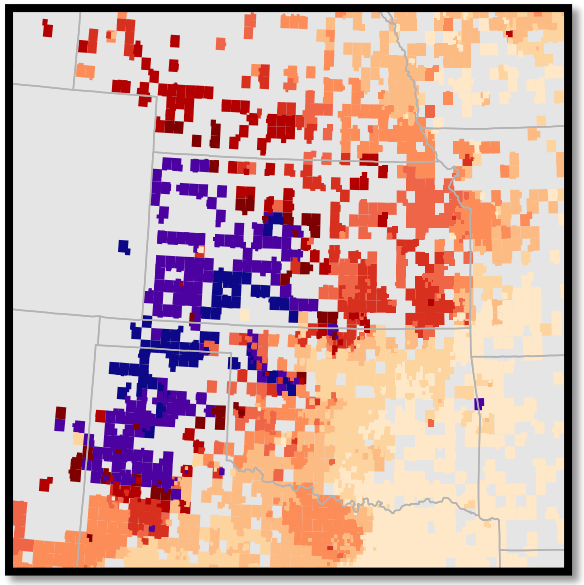
Maps show **negative pricing** is rising in ERCOT again

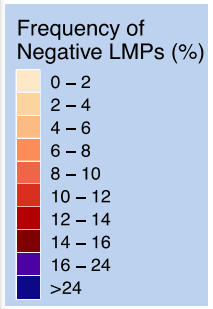


Other options for maintaining economic competitiveness:
Transmission to reduce congestion and move wind to load

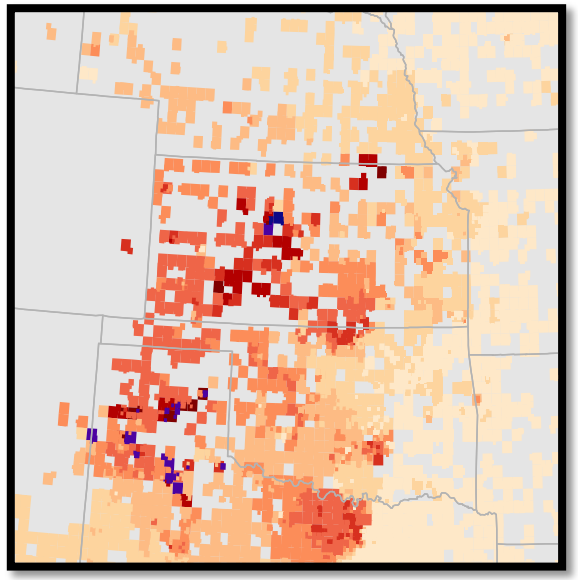
Transmission also reduced the frequency of negative prices and curtailment in the Southwest Power Pool (SPP), just from 2017 to 2018

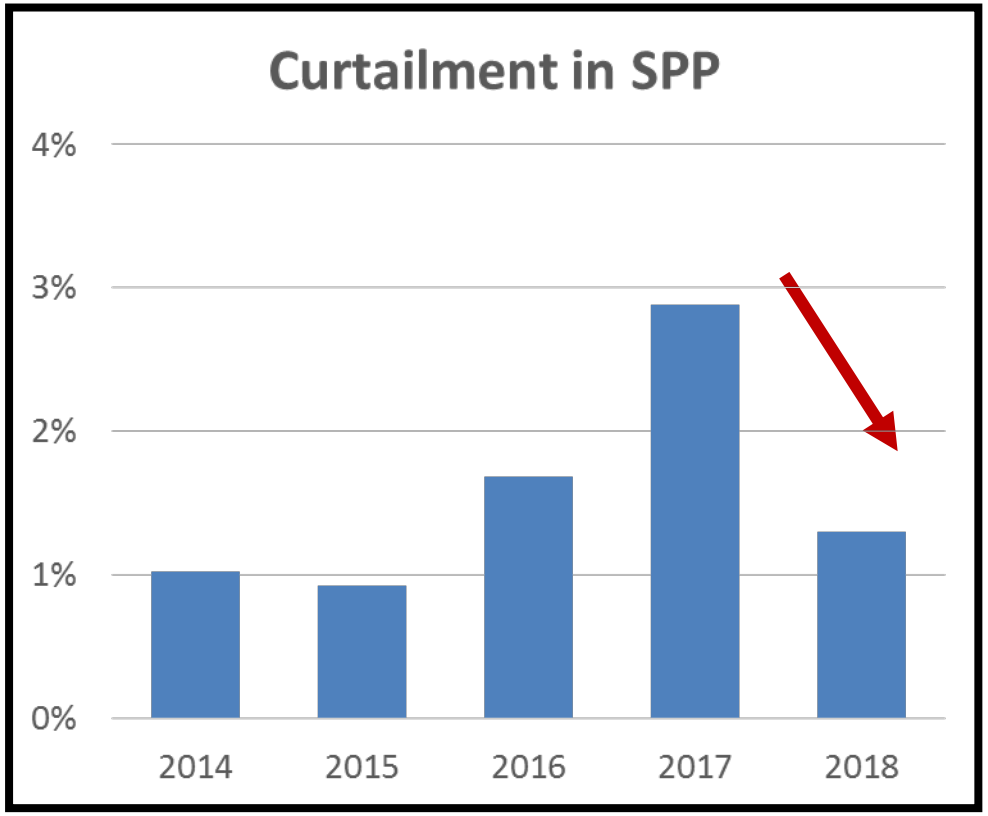
2017





2018





Widespread negative pricing need not always be permanent: transmission matters