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

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Electricity Markets and Policy Group Webinar

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

![Bar chart showing annual curtailment (%) for different transmission capacities.](source: NREL 2017)

Projected Transmission needs

![Graph showing projected transmission capacity needs from 2016 to 2048.](source: NREL Standards Scenarios)
Popular cost metrics like LCOE do not typically include system costs. 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?

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Source: Lazard 2018

<table>
<thead>
<tr>
<th>Energy Type</th>
<th>Levelized Cost ($/MWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar PV - Rooftop Residential</td>
<td>$100</td>
</tr>
<tr>
<td>Solar PV - Rooftop C&amp;I</td>
<td>$170</td>
</tr>
<tr>
<td>Solar PV - Thin Film Utility Scale</td>
<td>$44</td>
</tr>
<tr>
<td>Onshore Wind</td>
<td>$90</td>
</tr>
<tr>
<td>Gas Peaking</td>
<td>$126</td>
</tr>
<tr>
<td>Nuclear</td>
<td>$144</td>
</tr>
<tr>
<td>Coal</td>
<td>$143</td>
</tr>
<tr>
<td>Gas Combined Cycle</td>
<td>$74</td>
</tr>
</tbody>
</table>

**Note:** Does not consider system infrastructure needs and costs.
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 \sim \$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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Part I: Motivation and Introduction

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We assess transmission costs by relying on multiple sources

Four approaches:

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Geography considered</td>
<td>MISO, PJM, and EIA</td>
<td>Select regions within U.S.</td>
<td>Entire U.S.</td>
<td></td>
</tr>
<tr>
<td>Cost Responsibility</td>
<td>Developer</td>
<td>Developer (spur lines) and socialized (bulk)</td>
<td>Socialized</td>
<td></td>
</tr>
<tr>
<td>Project scopes</td>
<td>Generation project</td>
<td>Transmission system</td>
<td>Transmission project</td>
<td></td>
</tr>
<tr>
<td>Costs considered</td>
<td>Actual/study costs (POI and bulk system)</td>
<td>Modeled costs (bulk system and spur)</td>
<td>Actual costs (bulk system)</td>
<td></td>
</tr>
<tr>
<td>VRE amount</td>
<td>Individual projects</td>
<td>Both low and high penetrations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Generation types</td>
<td>All types</td>
<td>Utility-scale wind and solar only</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Key challenges</td>
<td>Limited bulk costs</td>
<td>Unrealistic optimizations</td>
<td>Coarse analysis</td>
<td>Selection bias</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ambiguous cost responsibility</td>
<td>Ambiguous cost responsibility</td>
</tr>
</tbody>
</table>
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

\[ LCOT \left( \frac{1}{(1+r)^{60}} \right) \div [K \times CF \times 8760] \]  
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

\[ LCOT = \frac{\sum_{n=0}^{N} \frac{c_n}{(1+r)^n} - \sum_{n=1}^{N} \frac{q_n}{(1+r)^n}}{\sum_{n=0}^{N} \frac{q_n}{(1+r)^n}} \]  
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
Part I: Motivation and Introduction

Part II: Estimation Methods

Part III: Results

- Approach I: Interconnection Studies
- Approach 2 and 4: Simulation Studies and Actual Projects
- Approach 3: Aggregation Method

Part IV: Conclusion
Interconnection costs for VRE slightly higher than for conventional generators

- 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.

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

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Notes: Combines MISO, PJM, and EIA data

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Unit cost by state and generator type

- Natural Gas: n = 813
- Solar: n = 454
- Wind: n = 822

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Unit cost by queue entry year

- Ranges represent 20th and 80th percentiles
- Natural Gas
- Solar
- Wind

Notes: Combines MISO, PJM, and EIA data
Part I: Motivation and Introduction

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  • Approach 1: Interconnection Studies
  • Approach 2 and 4: Simulation Studies and Actual Projects
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Part IV: Conclusion
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?

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

Source: Various (EEI, CPUC records)

- Should we include outside CA renewable resources which might have relied on these transmission expenditures?
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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
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  - 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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The work described here was funded by the Transmission Permitting and Technical Assistance Division of the U.S. Department of Energy’s Office of Electricity.
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
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

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

Widespread negative pricing need not always be permanent: transmission matters

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

Transmission costs for renewable energy
Widespread negative pricing need not always be permanent: transmission matters

Maps show negative pricing is rising in ERCOT again

2014 2017

Add’n 5 GW Wind In ERCOT

Frequency of Negative Prices (%)

- 0 – 2
- 2 – 4
- 4 – 6
- 6 – 8
- 8 – 10
- 10 – 12
- 12 – 14
- 14 – 16
- 16 – 24
- >24
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.
Widespread negative pricing need not always be permanent: transmission matters

Frequency of Negative Prices (%):
- 0 – 2
- 2 – 4
- 4 – 6
- 6 – 8
- 8 – 10
- 10 – 12
- 12 – 14
- 14 – 16
- 16 – 24
- >24