Are coupled renewable-battery power plants more valuable than independently sited installations?

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Integrating growing levels of variable renewable energy (wind and solar) may require strategies that enhance grid-system flexibility.

- **Storage** technologies can be used for enhanced flexibility.
- Due to **declining costs**, batteries have become a popular choice.

Developers have increasing interest in co-locating generation with batteries at the point of interconnection, rather than siting separately.

- **Siting choice** depends on multiple considerations...
- …which can also impact effective renewable integration.
Interconnection queues indicate that commercial interest in hybridization has grown.

Source: Berkeley Lab review of 37 ISO and utility interconnection queues

Note: Not all of this capacity will be built.
CAISO and the non-ISO west have dominate fraction of all proposed solar plants in hybrid configuration

- **Solar** hybridization relative to total amount of solar in each queue is highest in CAISO (89%) and non-ISO West (69%)

- **Wind** hybridization relative to total amount of wind in each queue is highest in CAISO (37%), and significantly less in all other regions

- **Battery** development is dominated by hybrids only in CAISO (where data is available)

### Table: Percentage of Proposed Capacity Hybridizing in Each Region

<table>
<thead>
<tr>
<th>Region</th>
<th>Wind</th>
<th>Solar</th>
<th>Nat. Gas</th>
<th>Battery</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAISO</td>
<td>37%</td>
<td>89%</td>
<td>0%</td>
<td>64%</td>
</tr>
<tr>
<td>ERCOT</td>
<td>6%</td>
<td>21%</td>
<td>34%</td>
<td>37%</td>
</tr>
<tr>
<td>SPP</td>
<td>4%</td>
<td>22%</td>
<td>33%</td>
<td>38%</td>
</tr>
<tr>
<td>MISO</td>
<td>5%</td>
<td>18%</td>
<td>0%</td>
<td>n/a</td>
</tr>
<tr>
<td>PJM</td>
<td>1%</td>
<td>19%</td>
<td>1%</td>
<td>n/a</td>
</tr>
<tr>
<td>NYISO</td>
<td>0%</td>
<td>5%</td>
<td>6%</td>
<td>2%</td>
</tr>
<tr>
<td>ISO-NE</td>
<td>0%</td>
<td>12%</td>
<td>0%</td>
<td>n/a</td>
</tr>
<tr>
<td>West (non-ISO)</td>
<td>14%</td>
<td>69%</td>
<td>6%</td>
<td>n/a</td>
</tr>
<tr>
<td>Southeast (non-ISO)</td>
<td>0%</td>
<td>13%</td>
<td>1%</td>
<td>n/a</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td>6%</td>
<td>34%</td>
<td>6%</td>
<td>n/a</td>
</tr>
</tbody>
</table>

*As of end of 2020*
Prior paper outlined the pros and cons of hybridization

- Economic arguments for hybridization (vs. standalone plants) focus on opportunities to reduce project costs and enhance market value.

- Not all of these drivers reflect true system-level economic advantages, e.g., the federal ITC and some market design rules that may inefficiently favor hybridization over standalone plants.

- Possible disadvantages of hybridization include operational and siting constraints.

- If reduced operational flexibility is, in part, impacted by suboptimal market design then this too does not reflect true system-level economic outcomes.

Read more:
Motivations and options for deploying hybrid generator-plus-battery projects within the bulk power system.
Is the paradigm shifting on how to site power plants?

- Historically, the electricity paradigm involved Balancing Authorities using transmission network to *optimize geographically disperse* technologies.

- Co-locating suggests *conventional wisdom might be changing*:
  - Transmission constraints?
  - Operational/cost synergies?
  - Federal incentives?
We only consider renewable-plus-battery hybrids due to current commercial interest in these applications.

Out of scope examples:

1. Multiple generation types (e.g. PV + wind)
2. Alternative storage types (e.g. wind + pumped storage, concentrating solar power)
3. Virtual hybrids with distributed technologies
4. Full hybrids with operational synergies
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Our analysis focuses on the 7 nodal markets in the United States

- The seven markets are diverse in their resource mixes and market characteristics
- All operate day-ahead and real-time energy markets
- Use nodal LMPs reflecting transmission congestion, unique compared to European counterparts
Calculation of value: market optimization

- **Optimization**
  - Price taker analysis means resources *do not* impact marginal price
  - **Optimistic**: maximizes real-time energy market revenue with perfect foresight
  - **Pessimistic**: develop optimal schedule with day-ahead prices → realized revenue calculated from real-time energy market

- **Key Inputs**
  - **LMP prices** at nodes with utility-scale solar, wind, and high volatility
  - Average annual capacity price allocated to production in **top 100 net load hours**
  - Regulation prices at ISO zonal level *used only as a sensitivity analysis*
  - PV profiles modeled from **weather data**, standard design assumptions
  - Wind profiles modeled from **ERA5** weather data, standard wind power curve

- **Key Outputs**
  - Energy, capacity, regulation revenues *(levelized using generation from VRE)*
Storage value adder metric used to understand value boost from adding battery to VRE

- Tracks both coupled project value and standalone VRE investment value at the same geographic location

- Particularly helpful in understanding the potential for coupled projects to mitigate the value deflation that occurs for a VRE generator in regions with high VRE penetrations

\[
\text{Storage value adder} = (E_{CP} + C_{CP}) - (E_{VRE} + C_{VRE})
\]

Coupled value - Standalone VRE value
Coupling penalty metric evaluates constraints involved with co-locating batteries at the same VRE location

- Subtract the market value of a co-located generator from the market value of a standalone VRE generator and storage plant sited at different locations.

- Considers up to 3 constraints:
  1. Reduced geographic options for battery siting
  2. Increased operational constraints due to infrastructure sharing (i.e. inverter / POI)
  3. Restrictions on grid charging

\[
\text{Coupling penalty} = ([E_{VRE} + C_{VRE}] + [E_S + C_S]) - (E_{CP} + C_{CP})
\]

Conceptual figure to frame coupling penalty
## Design decisions and parameters modeled

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
<th>Effect on coupled value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geospatial</td>
<td>1,763 pricing nodes</td>
<td>Price nodes with higher volatility will be more valuable for storage</td>
</tr>
<tr>
<td>Year</td>
<td>2012, 2014, 2015, 2017, 2019</td>
<td>Years with more renewable penetration become more valuable for storage</td>
</tr>
<tr>
<td>Dispatch algorithm</td>
<td>Perfect foresight; Day-ahead schedule</td>
<td>Perfect foresight leads to higher revenues through omniscient operation</td>
</tr>
</tbody>
</table>
| Point of Interconnection (MW) | VRE capacity; VRE + battery capacity | • More interconnection capacity $\rightarrow$ more revenue  
• Potentially limited impact of constraint due to storage discharging at different times than renewable profile |
| Grid charging              | Disallow grid charging; Allow grid charging | • Allowing grid charging increases arbitrage opportunities  
• Value depends on relationship of prices and renewable profile |
| Degradation penalty        | $5/MWh; $25/MWh                      | Increasing penalty reduces lower value margin cycles, decreasing revenue but limiting degradation |
| Storage Size (%)           | 50% of generator capacity            | More capacity $\rightarrow$ more revenue (though potentially diminishing returns)        |
| Storage Duration (hrs)     | 4 hrs                                | More duration $\rightarrow$ more revenue (though potentially diminishing returns)        |
We consider a number of sensitivities to evaluate the robustness of our results

**Default scenario:**
- No ancillary services
- 1.3 ILR AC-coupled solar
- Perfect foresight algorithm
- Disallow grid charging for the coupled system
- VRE capacity for coupled POI limit
- $5/MWh degradation penalty
- 4 hr duration battery
- 50% battery to generation ratio

<table>
<thead>
<tr>
<th>Six main sensitivities:</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1) Regulation reserves included in value</td>
</tr>
<tr>
<td>(2) 1.7 ILR DC-coupled solar</td>
</tr>
<tr>
<td>(3) Day-ahead schedule</td>
</tr>
<tr>
<td>(4) Allow grid charging</td>
</tr>
<tr>
<td>(5) VRE+storage capacity for coupled POI limit</td>
</tr>
<tr>
<td>(6) $25/MWh degradation penalty</td>
</tr>
</tbody>
</table>

N/A
N/A
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  - Storage value adder
  - Coupling penalty

- Conclusions
Motivating Research Questions

1. Can *market revenues* explain higher commercial activity in the *Western U.S.*?

2. Can they explain why commercial activity is *higher for solar than wind*?

3. Does the traditional concept of *independently siting* resources not apply to VRE and storage technologies?
Storage value adder higher in ERCOT and CAISO in 2019

- High value in **CAISO began to diverge** from other markets in 2015

- Prior to 2019, ERCOT had a storage value adder that was the **lowest of all ISOs**

- **No significant change** in the value adder between solar and wind couples, besides in CAISO
CAISO coupled projects help offset value deflation over the period between 2012 and 2019

- Value of standalone solar decreases significantly between 2012 and 2019 as solar penetration increases from 2% to 19% of generation.
- Coupled batteries almost offset this value decline
- ERCOT sees increase in both solar value and coupled value

Note: Value adder metric indicated by black number.
Results at individual nodes tend to follow the aggregated average in each ISO

- Suggests that results not driven by significant variation at the **nodal level** within a market

- ERCOT is a notable exception, where a few nodes in the west see substantially higher value

**Geospatial differentiation of storage value adder across nodes**
The value of standalone VRE and storage exceeds the value of coupled projects in our default case

- These results suggest **significant penalties** associated with co-locating VRE and battery technologies.

- We did not find serious divergences between ISOs overtime.

- NYISO is a **notable exception** where the penalty was higher than in other ISOs between 2012 and 2015.

**Aggregated coupling penalty across markets**

![Graph showing aggregated coupling penalty across markets](image-url)
Our high volatility node selection resulted in additional storage value compared to solar and wind nodes

- **Strong correlation** between annual standard deviation and corresponding standalone storage value (top graph)

- Median storage value at high volatility nodes is higher than the corresponding value at wind and solar nodes but there is *significant overlap* (bottom graph)
Sensitivity cases significantly reduce coupling penalty

- While average coupling penalty is $12/MWh in default case, it is reduced to $1/MWh when using a relaxed POI/grid charging constraint, a less volatile node, and the day ahead scheduling algorithm.

- Need to compare these penalties to potential cost savings of coupling including the investment tax credit and construction cost synergies.
Conclusions

- Commercial interest in coupled projects differs from *convention of independently siting* and operation of electricity facilities through cost-optimized dispatch via balancing authorities.

- We find that coupled projects can significantly boost standalone VRE value across all markets in the U.S.
  - Value boost ranges from $5-$16/MWh, depending on sensitivity case.
  - Biggest boost in CAISO, where coupled projects can offset value deflation.

- Still, there is a penalty to restricting the location to a wind or solar node.
  - Coupling penalty ranges from $1-$12/MWh, depending on sensitivity case.
  - Future siting decisions will need to consider nodal volatility more deeply.
  - Value of both the ITC (~$10/MWh) and project development cost reduction (~$5/MWh) could offset this penalty.
Questions?

- Contact information
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  - Andrew Mills
  - James Hyungkwan Kim
  - Dev Millstein
  - Ryan Wiser

Download all of our work at:
http://emp.lbl.gov/reports/re

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