Changes in the Economic Value of Variable Generation with Increasing Penetration Levels: A Pilot Study of California

Andrew Mills and Ryan Wiser
Lawrence Berkeley National Laboratory

Energy Roundtable Discussion:
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Motivation and objective

- **Motivation:** Resource procurement & investment decisions are more difficult with variable and unpredictable variable generation (VG)
  - Comparisons of the levelized cost of energy (LCOE) between new generation options, e.g., are insufficient to show relative economic attractiveness
  - Part of what is missing from simple LCOE comparisons is an evaluation of the economic value of the energy generated
- **Objective:** Use a long-run modeling framework to evaluate the economic benefits of several different VG technologies
  - Wind, single-axis tracking PV, and CSP with and without six hours of thermal energy storage (CSP$_6$ and CSP$_0$, respectively)
- **Tailored valuation framework:** consider long-run capacity expansion as well as high time resolution dispatch (hourly over a full year) and power plant operational constraints
  - Integration studies often ignore long-run capacity expansion
  - Capacity expansion studies typically exclude high temporal resolution dispatch and operational constraints
Key findings

- Solar has high value relative to wind and flat block at low penetration.
- Value of PV and CSP without thermal storage drop considerably with increasing penetration levels.
  - Decrease primarily driven by capacity value and energy value.
- At medium to high penetration, CSP with thermal storage is considerably more valuable than PV and CSP without thermal storage.
- The value of wind is largely driven by energy value and is lower than solar at low penetration.
  - At high penetration, value of wind > value of solar w/o storage.
- In some cases, increasing penetration of one VG technology does not decrease the value of power from another VG technology.
  - May be easier to hit high penetration targets with combinations of VG technologies compared to the same high penetration level with just one technology.
Primary caveats

• Postulates certain penetrations of renewable energy
  • Does not seek to “optimize” overall cost / design of electric system

• Narrow definition of economic value:
  • Avoided capital investment cost and variable fuel and O&M costs from other power plants in CA
  • Does not consider cost of renewable energy or transmission needs

• Focus on California without evaluation of transmission:
  • Renewable electricity only used to meet CA demand
  • Incumbent generation only includes generation in CA NERC region

• Marginal economic value instead of average value:
  • Only indicates value of next increment of VG

• Simplified commitment and dispatch decisions:
  • Vintages rather than individual unit commitment
### Investment and dispatch decisions with increasing PV penetration

<table>
<thead>
<tr>
<th>PV Penetration Incremental Reduction in Non-PV Capacity (GW)</th>
<th>Incremental Increase in Nameplate PV (GW)</th>
<th>Effective Marginal Capacity Credit (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0% - 5%</td>
<td>2.8</td>
<td>48%</td>
</tr>
<tr>
<td>15% - 20%</td>
<td>0.4</td>
<td>7%</td>
</tr>
</tbody>
</table>

**Table:**
- **Solar**
- **New_Gas_CC**
- **Exist_Gas_CT**
- **Exist_Gas_ST**
- **Exist_Gas_CC**
- **Exist_Coal_ST**
- **Exist_Geothermal**
- **Exist_Nuclear**
- **Exist_Hydro**
- **Exist_Storage**

**Diagram:**
- **Single-Axis PV**
- **Nameplate Capacity (GW)**
- **20%**
- **30%**
Marginal value of variable generation varies with technology and penetration.

- System becomes increasingly energy-limited in winter.
Times with high net load and high prices shift to early evening with increasing PV

Highest load hours are occur in late afternoon.

With high PV penetration, highest net-load hours occur in the early evening.

PV does not generate in early evening hours

High price periods shift from times with high load to times with high net-load

Contribution of high price hours to marginal economic value of PV declines with high PV penetration
Times with high net load remain similar with modest penetration of CSP6

Highest load hours are occur in late afternoon.

With CSP$_6$, highest net-load hours remain in the late afternoon.

CSP$_6$ extracts energy from thermal storage starting in the early evening.

High price periods remain in the late afternoon even with increasing CSP$_6$ penetration

Contribution of high price hours to marginal economic value of CSP$_6$ remains relatively high even at 15% penetration
PRELIMINARY
MITIGATION RESULTS

Focus on geographic diversity and technological diversity.

Additional cases not examined here include impact of low cost bulk power storage, more flexible conventional generation, and price responsive demand.
Marginal value of wind remains higher at geographically diverse sites

If wind sites were to be selected such that they maximize geographic diversity within WECC, the marginal value of wind would increase by up to $10/MWh at high penetration levels.
PV output follows the Sun: Little benefit of geographic diversity at high penetration.

PV sites in WECC will all have lower value as PV penetration increases. The benefit of additional geographic diversity is small.
In most cases, increasing one VG tech. does not decrease value of other VG tech.

**Wind**

- Does not decrease the value of PV
- Slightly increases the value of CSP6

**PV**

- Increases the value of wind
- Slightly decreases the value of CSP6

**CSP6**

- Does not decrease the value of wind
- Decreases the value of PV
Conclusions

• **Solar has high value at low penetration levels**
  • The high value is largely due to the high capacity value at low penetration

• **There is little apparent value to thermal storage for CSP plants at low penetration levels**

• **The value of PV and CSP without thermal storage drop considerably with increasing penetration levels**
  • Main driver is change in capacity value and energy value with increasing penetration
  • Day ahead forecast error and ancillary service costs do not change nearly as much with increasing penetration
Conclusions (con’t)

• At medium to high penetration CSP with thermal storage is considerably more valuable relative to PV and CSP without thermal storage

• The value of wind is largely driven by energy value and is lower than solar at low penetration
  • At high penetration, value of wind > value of solar w/o storage

• Hitting a high renewable target can be easier with combinations of VG technologies than it can be with one VG technology alone
  • Increasing PV penetration increases the value of wind
  • Increasing wind does not decrease the value of PV
For More Information

Listen to the CREPC Webinar:
http://westgov.adobeconnect.com/p2bc7cavm3e/

Download the full report:

Contact info:

Andrew Mills, ADMills@lbl.gov, (510) 486-4059

Ryan Wiser, RHWiser@lbl.gov, (510) 486-5474

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