Recent Photovoltaic Performance Data in the USA

Photovoltaic Module Reliability Workshop (PVMRW)
Golden, CO
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Outline

- Introduction
  - American Recovery & Reinvestment Act data
  - Performance relative to predicted
  - Reliability categories
  - First geographic trends
  - Impact of reliability categories
- Conclusion
Has the recent PV price decline led to reliability issues?

Recent Negative Headlines about Solar Industry
Quality issues threaten to give solar a black eye, PVTECH, F.Carus, 15 January 2013
How Bad Is PV Panel Performance?, IEEE Spectrum, B. Sweet, 30 May 2013

→ Documenting field performance data, especially on a large scale
Geographic Distribution of Systems

50,000 Systems  
1.7 Gwatts capacity  
Up to 4 years of data

Data filtering rules:
- Nameplate=production year1,2,3,4 → reject production years
- Predicted capacity factor: Predicted AC energy/(24*365*DC rating)*100= 3-40%
- Year1 production = Year2 production → reject year2 entry
- Annual production = predicted production → reject

Data available:
- AC production, Predicted AC production
- Zip code location
- Nameplate
- Comments

Not available:
- Insolation
- Orientation

American Recovery & Reinvestment Act, Section 1603
No Evidence of Massive failure

Year of Operation:

- **Year 1**: 48,259 Data Points
  - Normal: 91.5%
  - Hardware: 0.7%
  - Project: 0.8%
  - Weather: 5.8%
  - Data Collection: 0.9%
  - No information: 0.2%

- **Year 2**: 18,632 Data Points
  - Normal: 95.3%
  - Hardware: 0.6%
  - Project: 1.0%
  - Weather: 1.3%
  - Data Collection: 0.9%
  - No information: 0.9%

- **Year 3**: 5,825 Data Points
  - Normal: 97.6%
  - Hardware: 0.5%
  - Project: 0.1%
  - Weather: 0.7%
  - Data Collection: 0.6%
  - No information: 0.7%

- **Year 4**: 479 Data Points
  - Normal: 95.8%
  - Hardware: 0%
  - Project: 0.2%
  - Weather: 2.3%
  - Data Collection: 0.8%
  - No information: 0.8%

**Project/Site:** Delay, grid interconnection, construction etc.

**Weather:** Snow, soiling, lightning, hurricanes etc.

**Data Collection:** Data acquisition, less than a year of data, etc. (not performance related)

**Hardware:** Inverter, module, breaker, fuses etc.
Most systems produce as expected

Measured vs. predicted production for all operation years

Project issues data points tend to be farther away from unity line → They don’t occur that often (previous slide) but if they do they tend to have larger impact
Ca. 90% of normal data produce at least 90% of predicted production

Normal data produce a few percent more than expected
→ may have significant impact on performance based incentive programs

<table>
<thead>
<tr>
<th></th>
<th>Year1</th>
<th>Year2</th>
<th>Year3</th>
<th>Year4</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Median / Stdev</strong></td>
<td></td>
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<tr>
<td>Normal</td>
<td>1.05 ±</td>
<td>1.06 ±</td>
<td>1.04 ±</td>
<td>1.03 ±</td>
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<td></td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
<td>0.13</td>
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<tr>
<td>Project</td>
<td>0.84 ±</td>
<td>0.61 ±</td>
<td>0.29 ±</td>
<td>-</td>
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<tr>
<td></td>
<td>0.24</td>
<td>0.37</td>
<td>0.36</td>
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<tr>
<td>Data Collection</td>
<td>0.90 ±</td>
<td>0.76 ±</td>
<td>0.71 ±</td>
<td>0.65 ±</td>
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<tr>
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<td>0.41</td>
<td>0.35</td>
<td>0.21</td>
<td>0.19*</td>
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<tr>
<td>Hardware</td>
<td>0.86 ±</td>
<td>0.77 ±</td>
<td>0.74 ±</td>
<td>0.74 ±</td>
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<tr>
<td></td>
<td>0.23</td>
<td>0.24</td>
<td>0.18</td>
<td>0.42*</td>
</tr>
<tr>
<td>Weather</td>
<td>0.87 ±</td>
<td>0.78 ±</td>
<td>0.45 ±</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>0.22</td>
<td>0.20</td>
<td>0.29*</td>
<td></td>
</tr>
<tr>
<td>No information</td>
<td>0.25 ±</td>
<td>0.48 ±</td>
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<td></td>
<td>0.37</td>
<td>0.47</td>
<td>0.16</td>
<td>0.12*</td>
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</tbody>
</table>

* Indicates less than 10 data points
No trend with nameplate rating

Yield (AC energy/nameplate rating) vs. nameplate & year

- **Year 1**: Mean yield: 1444± 282 kWh/kW
- **Year 2**: Mean yield: 1454± 278 kWh/kW
- **Year 3**: Mean yield: 1450± 258 kWh/kW
- **Year 4**: Mean yield: 1427± 208 kWh/kW

Yield appears wider for smaller systems → caused by higher point density
No trend with nameplate rating

Yield (AC energy/nameplate rating) vs. nameplate & year

Year 1

Mean yield: 1444 ± 282 kWh/kW

Year 2

Mean yield: 1454 ± 278 kWh/kW

Year 3

Mean yield: 1450 ± 258 kWh/kW

Year 4

Mean yield: 1427 ± 208 kWh/kW

Yield appears wider for smaller systems → caused by higher point density
Yield distributions similar for different system size

Note: individual histograms have different count scales

AC yield
Nameplate rating

Distribution shapes for the AC yield for different rating bins as a function of year
Data collection issues fall by order magnitude

Data collection-related issues

Year 1

Year 2

Year 3

DAQ: data acquisition problem such as data transmission problem, internet outage etc. Missing data: Less than a year before data were entered

Mean missed time (months)

Less than 1 year: 2.1
DAQ Problem: 3.5

Less than 1 year: 2.2
DAQ Problem: 4.5

Less than 1 year: 2.1
DAQ Problem: 5
Project-related issues are dominated by delays

- **Delay**: Permitting & construction
- **Utility**: Grid interconnection
- **Construct.**: Roof repair, remodeling...
- **Fire**: fire at site not caused by PV → PV was turned off as precaution
- **Design**: addition of new part-array @ different orientation
- **Financials**: shutdown due to foreclosure
- **Not used**: PV system not used as often

- Delay & grid interconnection dominates 1st year, rapidly declines in subsequent years
- Construction shows small percentage increase over years
- Fire can have broader impact due to precautionary PV system shutdown
- Financial reasons correlated to states with large housing price cycles
Hardware-related issues are dominated by inverter

Repair: Unspecified repair & outages
Unauthorized shutdown: May be mitigated by interconnect locks

Less than 0.1% are due to defective modules
Weather-related issues dominated by snow & hurricanes

Hurricane: Typically, down time due to grid outage, not because of damage to system
Lightning: Not direct hits to PV system but transformer
Annual loss impact (%) of different categories

Performance in anomalous year compared to normal year → loss estimation due to cause of anomaly (assumes the same annual production)

Diamonds: 95% confidence interval
Crossbar: Mean

Module recalls do not occur often but if they do they can have large impact
Conclusion

- Analyzed field performance of 50,000 PV systems
- More than 90% of normal systems produce at least 90% of expected
- Project problems may not occur as often but have large impact
- Project-related problems are dominated by delays in the first year of operation, then rapidly declines in subsequent years.
- Hardware issues dominated by inverter, particularly in the first year of operation
- Less than 0.1% are due to defective or underperforming modules
- Module recalls can lead to significant annual production losses
- Weather-related issues are dominated by snow and hurricanes
Acknowledgments

Thank you for your attention

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