Quantifying Gains in Solar Project Value from Quality Satellite & Ground Data

May 23, 2017
Skip Dise, Clean Power Research
Forces Shaping the Energy Transformation

- Digital Users
- Changing Electric Resource Mix
- Consumer Behavior
- Power Generation
- Increasing Interest in Energy Products
- Distribution Optimization
TODAY’S FOCUS

- Quality & Type of Ground Measurements
- Use of SolarAnywhere Satellite Data
- Impacts on Project Uncertainty
- Gains in Project Value
- Return on Ground Campaign
BEYOND THE SCOPE

- TMY3 or other public data set comparisons
- Shifts in P50 from satellite to ground tuning
- Factors unrelated to solar resource uncertainty
- Bank negotiated financial terms
- Probability of Exceedance methods
TIGHTENING UNCERTAINTY OF P99

Investment in Ground Measurements Can Increase P99
• Version 3.2
• Data Validated and Widely Accepted
• Uncertainty Rate Known and Accepted
• Long History and Data Currency
• Spatially Precise
• Built for Solar

Source: https://www.solaranywhere.com/validation/leadership-bankability/
BEST PRACTICES FOR GROUND MEASUREMENT

• High quality, maintained instrumentation
• Redundant irradiance measurements
• 1 year minimum campaign, 2 preferred¹
• Weekly technician visits
• Actionable data quality program
• Descriptive metadata

Secondary Standard GHI
Secondary Standard GHI
+ GroundWork PVSOIL
Secondary Standard GHI
+ GroundWork PVSOIL
+ Diffuse
Secondary Standard GHI
+ Diffuse
+ DNI
## SOLAR PROJECT UNCERTAINTY FACTORS

<table>
<thead>
<tr>
<th>Factor</th>
<th>Data Source</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Resource</td>
<td>Ground and/or satellite irradiance</td>
<td>3.0-5.0%</td>
</tr>
<tr>
<td>Interannual Variability</td>
<td>Satellite history</td>
<td>2.5-8.0%</td>
</tr>
<tr>
<td>Transposition to Plane of Array</td>
<td>Decomposition: modeled or ground diffuse irradiance Transposition: calculated</td>
<td>3.5-12.7%</td>
</tr>
<tr>
<td>Soiling</td>
<td>Estimated or ground soiling studies</td>
<td>1.0%-4.0%</td>
</tr>
<tr>
<td>Energy Simulation, Plant Loss and Degradation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
TOTAL PROJECT UNCERTAINTY

\[ \varepsilon_p = \sqrt{\varepsilon_p^2 + \varepsilon_{\text{Solar Resource}}^2 + \varepsilon_{\text{Interannual Variability}}^2 + \varepsilon_{\text{Transposition to Plane of Array}}^2 + \varepsilon_{\text{Soiling}}^2 + \varepsilon_{\text{Other Model Factors}}^2} \]

Root Sum of the Squares
• Satellite data is tuned with ground data
• Component sum GHI eliminates cosign error of secondary standard pyranometer

<table>
<thead>
<tr>
<th>Source</th>
<th>Ground</th>
<th>Tuned Satellite</th>
</tr>
</thead>
<tbody>
<tr>
<td>SolarAnywhere V3.2 GHI</td>
<td>n/a</td>
<td>5%</td>
</tr>
<tr>
<td>Secondary Standard GHI</td>
<td>3.5%¹</td>
<td>2.6%</td>
</tr>
<tr>
<td>Component Sum GHI</td>
<td>2.1%²</td>
<td>2.6%</td>
</tr>
</tbody>
</table>

2. Ibid.
INTERANNUAL VARIABILITY

Uncertainty is climate dependent (example site shown here)

- Annualized and 4-month cumulative distribution functions (CDFs)

<table>
<thead>
<tr>
<th>Source</th>
<th>Low Interannual Variability</th>
<th>High Interannual Variability</th>
</tr>
</thead>
<tbody>
<tr>
<td>SolarAnywhere V3.2</td>
<td>2.5%</td>
<td>8.0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Yearly Dissection</th>
<th>Data Points</th>
<th>Avg (µ)</th>
<th>Std dev (σ)</th>
<th>RE (σ/µ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Whole Year</td>
<td>18</td>
<td>2,029,496</td>
<td>57,712</td>
<td>2.84%</td>
</tr>
<tr>
<td>Four-month</td>
<td>5,832</td>
<td>2,029,023</td>
<td>50,270</td>
<td>2.48%</td>
</tr>
</tbody>
</table>

\[+0.341 (σ)\]
\[-0.341 (σ)\]
TRANSPOSITION TO POA

Uncertainty comprises Decomposition and Transposition to POA
- Decomposition models estimate DHI and DNI given GHI
- Can estimate or measure DHI
- Transposition to POA is calculated based on plant type

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modeled Diffuse</td>
<td>12.7%&lt;sup&gt;1,2&lt;/sup&gt;</td>
</tr>
<tr>
<td>Measured Diffuse</td>
<td>8.0%&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>Measured Tracking DNI/Diffuse</td>
<td>2.1%</td>
</tr>
</tbody>
</table>

1. Gueymard, C.A., From Global Horizontal To Global Tilted Irradiance, Solar 2008 ASES
2. Lave, M et al., Evaluation of Global Horizontal Irradiance to Plane of Array Irradiance Models at Locations across the United States, Sandia PV Performance Workshop
SOILING RATES

- Blanket annual estimate between 1-5%
- Measured soiling allows for determination of soiling ramp rates
- Can confidently model:
  - Monthly estimates
  - Max soiling value
  - Frequency of precipitation (cleaning) events

<table>
<thead>
<tr>
<th>Source</th>
<th>Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Estimated</td>
<td>4.0%</td>
</tr>
<tr>
<td>Measured – GroundWork PVSOIL</td>
<td>1.0%</td>
</tr>
</tbody>
</table>

Source Uncertainty
Estimated
-
- Measured – GroundWork PVSOIL
1.0%
### QUANTIFYING GAINS: FINANCIAL ASSUMPTIONS

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>CapEx Cost</td>
<td>$1.50/ watt</td>
</tr>
<tr>
<td>Unlevered ATIRR</td>
<td>7%</td>
</tr>
<tr>
<td>Gross Margin</td>
<td>75%</td>
</tr>
<tr>
<td>Debt Term</td>
<td>20 years</td>
</tr>
<tr>
<td>Debt Rate</td>
<td>5%</td>
</tr>
<tr>
<td>Debt Size</td>
<td>1.0 P99 DSCR</td>
</tr>
<tr>
<td>NPV Discount Rate</td>
<td>8%</td>
</tr>
</tbody>
</table>
## PROJECT VALUE GAINS

<table>
<thead>
<tr>
<th>Ground Measurements</th>
<th>Project Uncertainty</th>
<th>NCF_{p99} %</th>
<th>$/W Gain</th>
<th>ROI on 25MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Satellite Only</td>
<td>10.2%</td>
<td>19.5%</td>
<td>Baseline</td>
<td>Baseline</td>
</tr>
<tr>
<td>Satellite + Secondary Standard GHI</td>
<td>8.6%</td>
<td>20.5%</td>
<td>$0.011</td>
<td>5.3X</td>
</tr>
<tr>
<td>Satellite + Secondary Standard GHI + Soiling</td>
<td>8.4%</td>
<td>20.6%</td>
<td>$0.012</td>
<td>5.0X</td>
</tr>
<tr>
<td>Satellite + Secondary Standard GHI + Diffuse + Soiling</td>
<td>6.6%</td>
<td>21.7%</td>
<td>$0.022</td>
<td>8.8X</td>
</tr>
<tr>
<td>Satellite + Secondary Standard GHI + DNI/Diffuse + Soiling</td>
<td>4.9%</td>
<td>22.7%</td>
<td>$0.035</td>
<td>8.3X</td>
</tr>
</tbody>
</table>
QUESTIONS & ADDITIONAL RESOURCES

• Literature:
  - https://www.solaranywhere.com/validation/leadership-bankability/

• Recorded Webinar:

• 5 Factors of Bankable Solar Resource Data:

• Company Websites:
  - https://www.grndwork.com
  - https://www.cleanpower.com or https://www.solaranywhere.com
Questions and Answers

Thank you for joining us

Additional Questions?
Skip Dise, skipdise@cleanpower.com
YOUR PARTICIPATION

Open and hide your control panel

Join audio:
- Choose “Mic & Speakers” to use VoIP
- Choose “Telephone” and dial using the information provided

Submit questions and comments via the Questions panel

Note: Today's presentation is being recorded and will be provided within 48 hours.
PRESENTERS

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GroundWork
Poll Question
Poll Question
Poll Question
• Solar industry leader for MET equipment and services
• Early entrant working with NREL in 2008
• HQ in Monterey California
• Shop in Southern California
• US, Mexico and Canada
• 40 full time staff