Uncertainty quantification of PV annual energy estimates in the System Advisor Model

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Abstract

Uncertainty in photovoltaic (PV) annual energy estimates is a key modeling area in which growth and better understanding is needed. The main concern is a lack of rigorous methodologies for uncertainty quantification that is accepted by the PV industry. Uncertainty in energy production estimates arises from variability of the solar resource, inexact PV performance models and their parameters, and system reliability considerations. Uncertainty in annual energy production is frequently calculated for PV projects to quantify financial risk. Key statistics for energy, such as the P- values “P50” and “P90” are used by financing institutions to calculate the repayment risk for the project. The current methods to estimate these statistics are typically proprietary, specialized, and involve significant post-processing of commercial performance model results. This black-box approach leads to inconsistent P-value estimates from different parties, which reduces investors’ confidence in the results. The new uncertainty quantification methods proposed here offer a standardized methodology in which modeling factors are assigned uncertainty distributions that are then applied in Monte Carlo analysis in conjunction with inter-annual variability analysis (IAV) to generate P-values on annual energy. Separating the uncertainty from modeling factors and the IAV helps to better communicate energy yield modeling uncertainty and leads to better investment decisions. The methodology presented here is available in the 2022.11.21 version of the System Advisor Model (SAM).

Methodology

- Separate the uncertainty in PV annual energy estimation into two categories: **aleatory uncertainty** and **epistemic uncertainty**
- **Aleatory uncertainty** : uncertainty stemming from the randomness of variables that cannot be better known or understood. The main source for this category is inter-annual variability (IAV) in weather data across years.
- **Epistemic uncertainty** : uncertainty from modeling parameters, data, and model equations that can theoretically be improved through improvements in models or more accuracy in data measurement.
- Epistemic uncertainty is estimated with factors for each modeling component that represents uncertainty in annual energy estimates due to each factor
- Factors are treated as a distribution that are then sampled through Monte Carlo methodology and applied to a base annual energy value to generate a distribution of annual energy values for base weather year [1]
- Process is repeated for n weather years provided by modeler with same factor distribution set
- Results show impacts of aleatory and epistemic uncertainty separately along with the combined uncertainty and Pxx probability of exceedance values

Uncertainty factors

- Factors chosen based on previous IEA Task 13 work, understanding of model chain for PV annual energy estimates [2]
- First-order factors: more impact on annual energy estimates, wider uncertainty distributions
- Second-order factors: less sensitivity in annual energy, narrower distributions
- Other factors not listed: Effects of snow and soiling loss
- Factor distributions can be normal, uniform, triangular distribution, etc.

First-order PV annual energy uncertainty factors

First-order factors	Definition
Irradiance transposition	uncertainty in modeling to go from GHI to incident irradiance
Shading (horizon and local)	Modeling of shading effects reducing incident irradiance
Standard test conditions (STC) power	Uncertainty in methods used to get module STC rating
Inverter availability	Lack of knowledge on inverter downtime

Second-order PV annual energy uncertainty factors

Second order factors	Definition
Spectral response	model adjustments based on wavelength of light
Cell temperature	Cell temperature modeling uncertainty
Mismatch loss	Model of mismatch of performance within string or array
Electrical loss	Voltage losses from wiring or transformer losses

- Ground irradiance measurement uncertainty was quantified as part of this project, normal distribution on annual energy ranges from mean [-0.4%, 0.4%] and std. dev. [0.35%, 0.6%] [3]
- Bifacial modeling uncertainty (view factor approach) distributions on annual energy found to be [-.04%, .04%] mean and [.08%, .22%] std. dev [4].

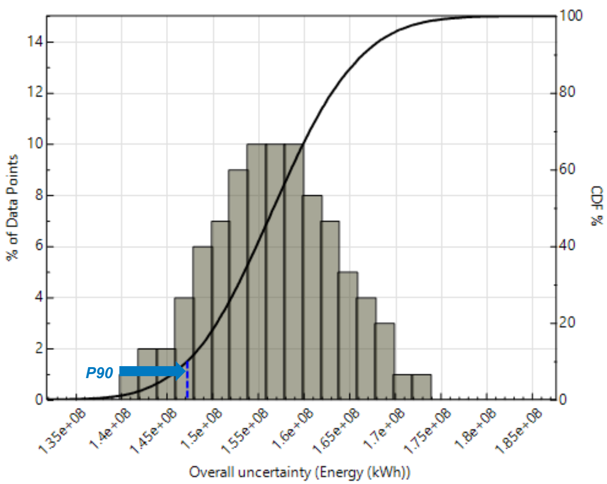
Discussion

- **Would you consider incorporating the methodology presented here into your modeling workflow?**
- **How do you currently model uncertainty in your annual energy estimates?**
- **What are your experiences with systems under- or over-performing probability of exceedance estimates?**
- **Which uncertainty factor do you struggle the most to quantify? Are there factors not listed here that we should consider?**

Uncertainty Modeling in SAM

Uncertainty factor distribution default definitions

Factor	Dsitribution type	Parameters
Irradiance transposition	Normal	μ = 11.5, σ= 2.5
Horizon shading	Triangular	min.=-1, mode=0, max.=0
Row shading	Triangular	min.=-5, mode=-1, max.=0
Single module rating at STC	Normal	μ = 0, σ= 2.0
Spectral response.	Triangular	min.=-5.7, mode-2.70, max.=0
Inverter availability	Normal	μ = -1, σ= 0.5
Cell temperature	Normal	μ = -2.4, σ= 1.0
Mismatch loss	Triangular	min.=-1.8, mode=-0.8, max.=0
DC wiring	Triangular	min.=-2.5, mode=-1.5, max.=-1
Transformer	Triangular	min.=-2, mode=-1, max.=-0.5
Soiling	Triangular	min.=-1.5, mode=-0.5, max.=0



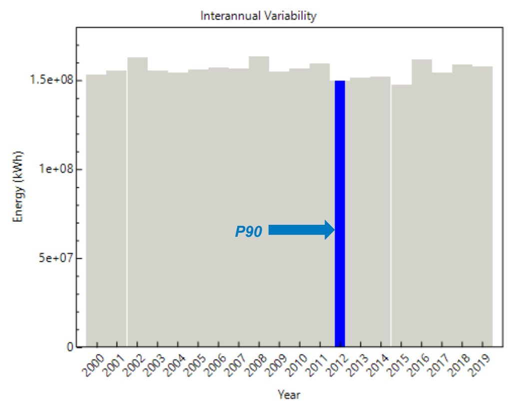
Combined uncertainty results

Probability of exceedance results (blue lines)

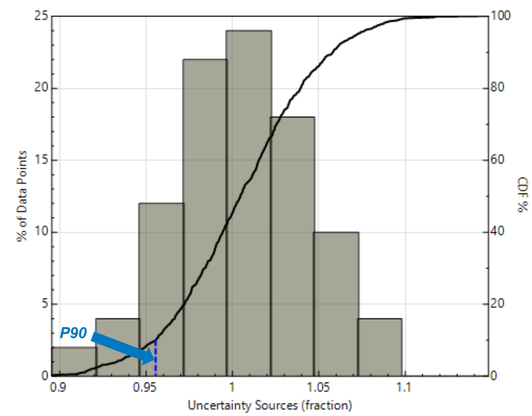
P90 value	Value
Combined uncertainty	1.47224e8 kWh
IAV uncertainty	1.49776e8 kWh
Factor uncertainty fraction	0.955788

System specifications for example uncertainty analysis

System Spec	Value
System capacity	100 MWDC
Tracking	Single-axis tracker E-W
Location	Golden, CO
Weather years	2000 - 2020



Aleatory uncertainty results



Epistemic uncertainty results

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