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Uncertainty in P90 of Energy Yield

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Outline

- What is P90 and why is it uncertain?
- Typical practice to calculate P90
- An alternative: a structured approach to uncertainty
- Uncertainty due to modeler skill

What is P90 and why is it “uncertain”?

P90 is the 10th percentile of the distribution of future annual energy

Estimated future annual energy is uncertain due to uncertainty in:

- Future weather
- Historical weather data (when used to represent future weather) - data have measurement (or modeling) uncertainties
- Models and parameters that are used to translate weather to annual energy
- Modeler skill

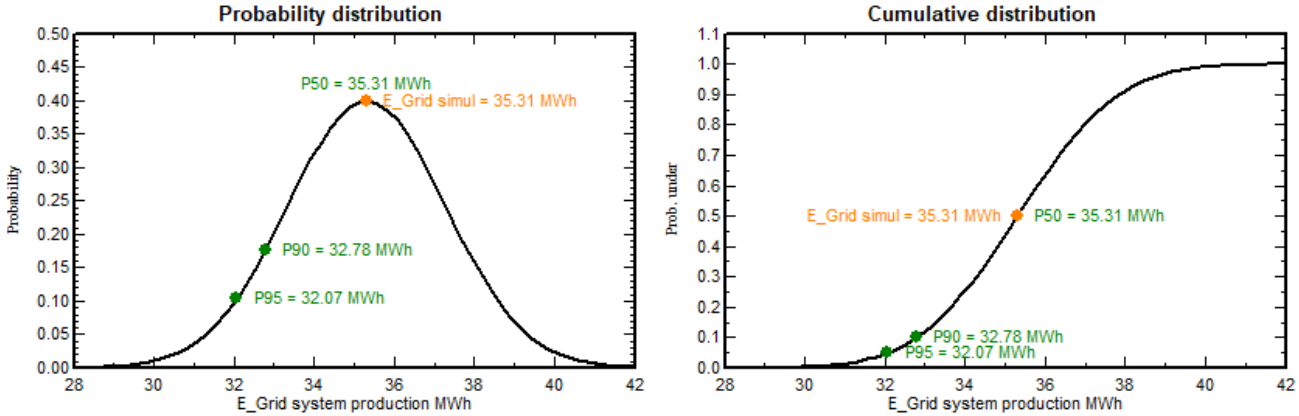
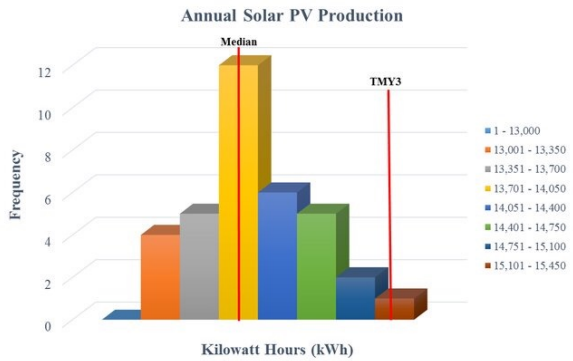


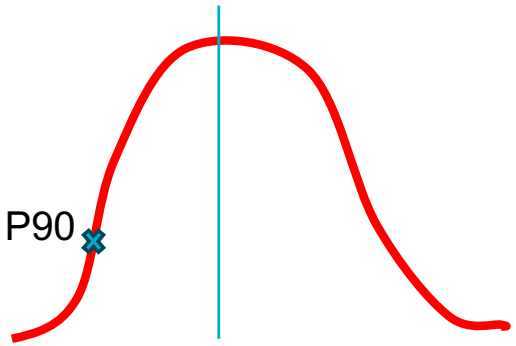
Figure courtesy of PVsyst, https://www.pvsyst.com/help/p50_p90evaluations.htm

Typical practice to calculate P90 (“All-in” approach)

1. Model future weather, by assuming either:
   A. Multiple years of historical weather
   B. A typical year of weather
2. Select models (and parameters) and calculate average (or typical) annual energy
3. Account for model/data uncertainties
   A. Form a distribution with the average (typical) annual energy as a central value
   B. “Widen” the distribution using a variance

$\sigma = \sqrt{\sum_k \sigma_k^2}$, where σ_k is the variance of annual energy attributable to some source of uncertainty





https://eepower.com/technical-articles/understanding-the-role-of-uncertainty-in-pv-energy-production
https://solargis.com/blog/best-practices/how-to-calculate-p90-or-other-pxx-pv-energy-yield-estimates
https://www.pvsyst.com/help/p50_p90evaluations.htm

Shortcomings of the “all-in” approach

All-in approach yields a single value for P90

- An (imprecise) estimate of the 10th percentile of future annual energy
- “All-in” method provides no means to quantify this lack of precision

All-in approach conflates uncertainty in future weather with uncertainty in models and data

- Future weather is inherently unknowable
- Uncertainty in models and data can (in theory) be reduced
- Does not provide a basis to judge the value of improving models and data

A structured approach to uncertainty

Aleatory *(inherent, random)* uncertainty that cannot (practically) be reduced by better measurements or models

- Future weather is inherently variable and (at some precision) unknowable

Epistemic *(state-of-knowledge)* uncertainty that could, in principle, be reduced by more accurate measurements, better models, more data, etc.

- E.g., a temperature coefficient could be known more precisely with more data, or, variation among PV modules could be quantified with more testing.

Structured approach is commonly used in environmental and engineering risk assessments

Structured approach yields same P90 but with more information

“All-in” P90 “=“ Inherent uncertainty from future weather “+“ Reducible uncertainty from models and data

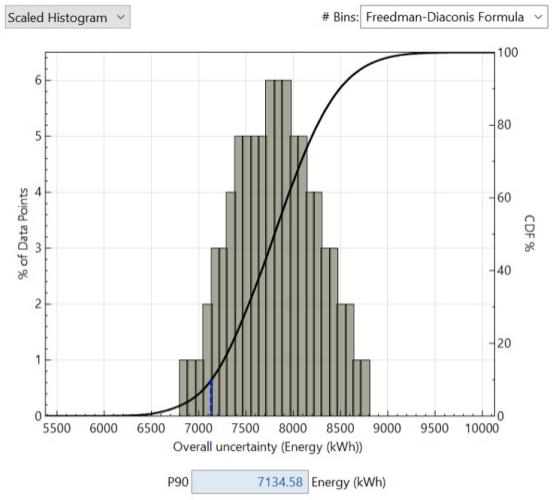


Figure 1. Combined uncertainty graph from SAM uncertainty tool

“=“

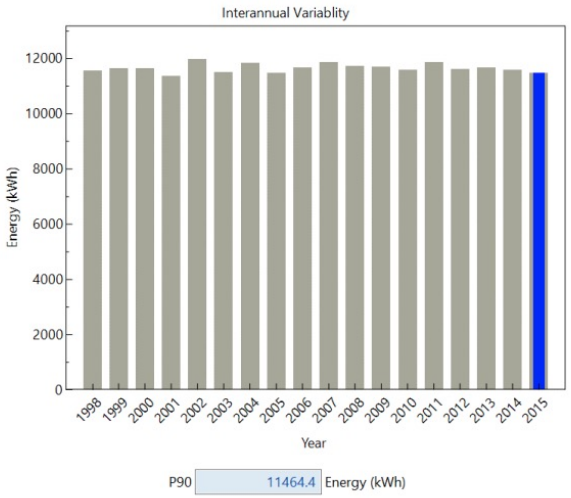


Figure 2. Weather uncertainty graph from SAM uncertainty tool

“+“

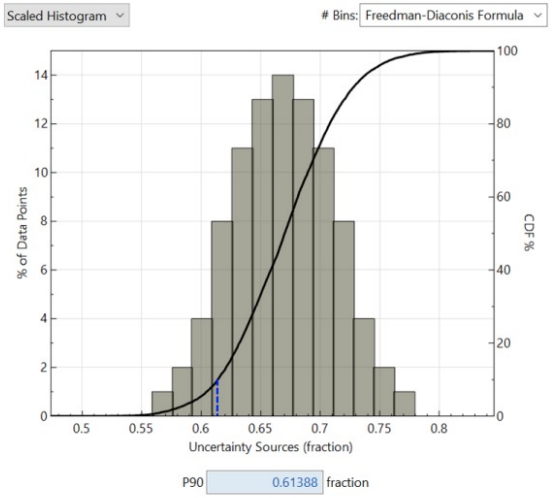


Figure 3. Uncertainty factor graph from SAM uncertainty tool

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Uncertainty in Annual Yield: Conceptual Approaches and Implementation in SAM

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How the structured approach can be applied to yield assessment

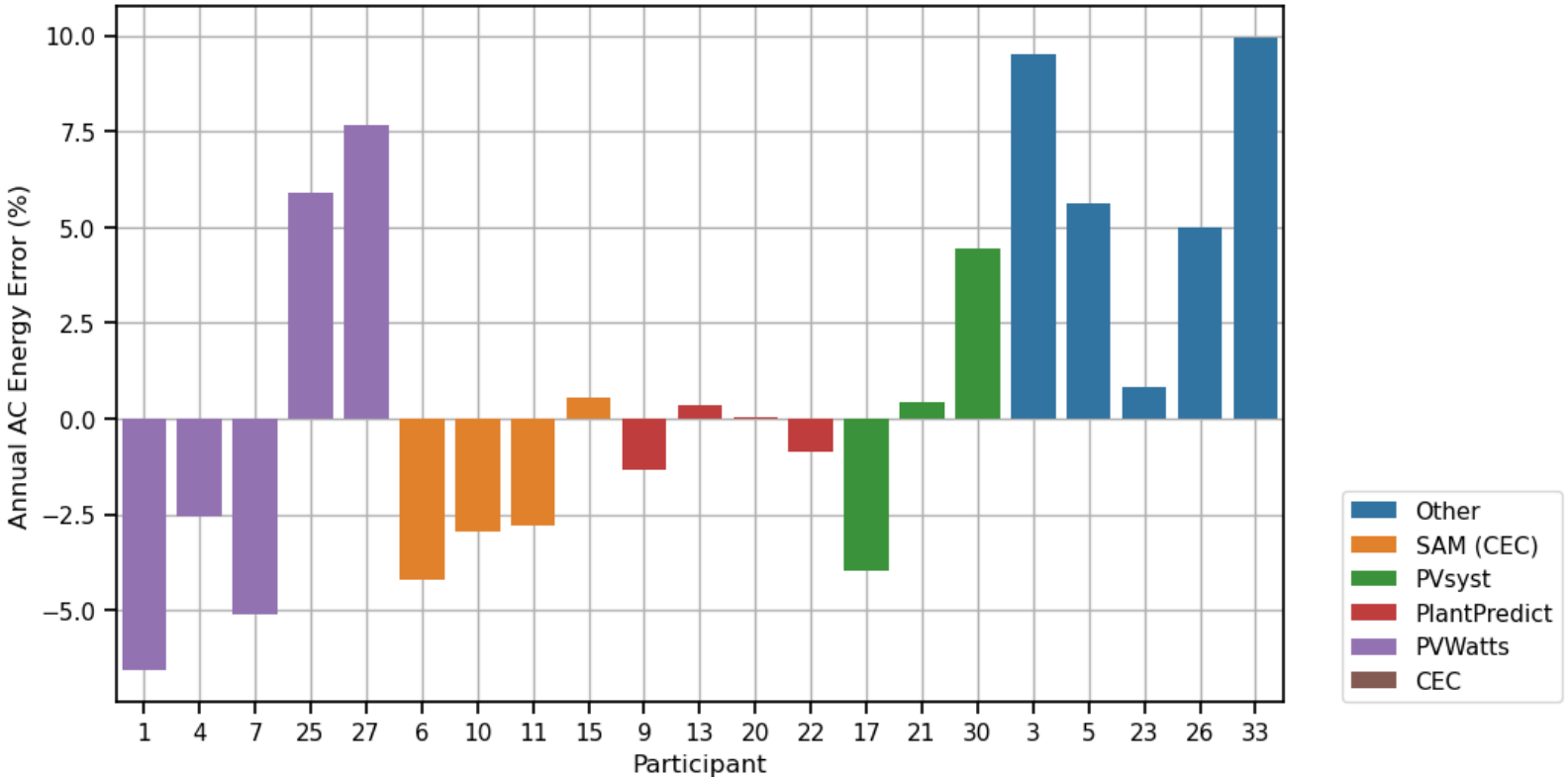
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Modeler skill contributes to uncertainty in P90



From 2023 blind modeling comparison (Deville et al., 2024 PVPMC)

Summary

Separating weather from model and data uncertainties:

- Gives same overall P90
- Quantifies the relative influences of
  - Weather variability
  - Model/data uncertainty
- Quantifies the precision in P90

How do we reduce uncertainty due to modeler skill?

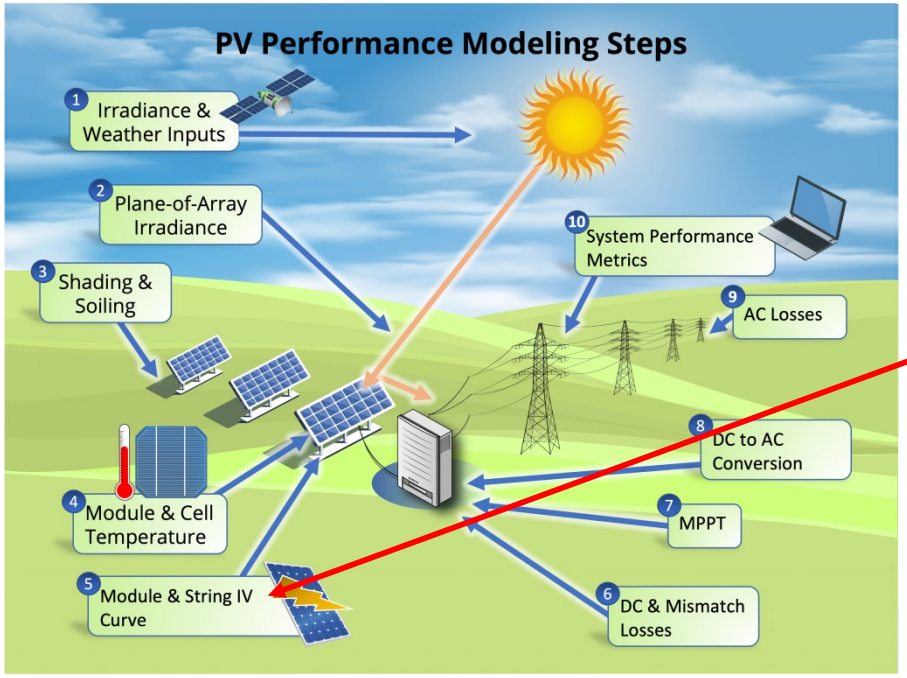
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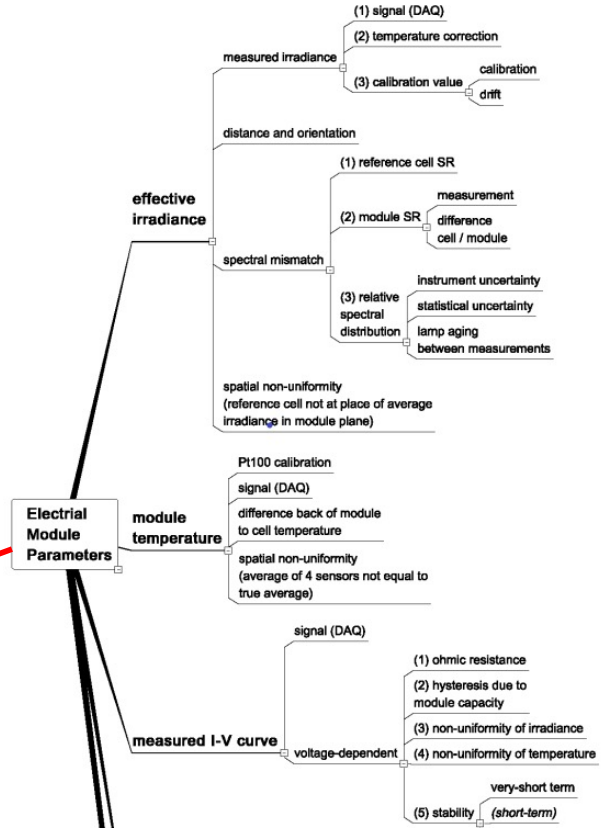
Quantifying epistemic (model, parameter) uncertainty

Quantify uncertainty in parameters and models

Propagate to annual energy

“Bottom-up approach” is <u>impractical</u>





D. Dirnberger and U. Kräling (2013)
doi: 10.1109/JPHOTOV.2013.2260595.

Top down “annual energy factors” approach

“Annual factors” approach recommended by IEA PVPS Task 13 [1]

Combined with the structured approach for uncertainty (implemented in SAM) [2]

Annual variability in weather is separated from all other uncertainties

- For each year of weather W :
- “Base” annual energy $\overline{Y}$ (using “best estimate” models)

$$\overline{Y}(W) = f(W; \mathbf{p})$$

- Apply a set of “uncertainty factors” F_k to generate a distribution Y of annual energy

$$Y(W) = \overline{Y} \times \prod_k (1 - F_k)$$

- Repeat for all years W (e.g., when using historical data)

1. “Uncertainties in PV System Yield Predictions and Assessments”, Reise et al. (2018), IEA-PVPS T13-12:2018
https://iea-pvps.org/wp-content/uploads/2020/01/Uncertainties_in_PV_System_Yield_Predictions_and_Assessments_by_Task_13.pdf
2. “Quantifying Uncertainty in PV Energy Estimates Final Report”, Prilliman et al. (2023), NREL/TP-7A40-84993
https://www.nrel.gov/docs/fy23osti/84993.pdf

What are “uncertainty factors”?

Each F_k quantifies uncertainty in the base annual energy from some component model or parameter in the performance model chain.

- F_k has units of fraction of annual energy
- By convention, F_k is a “loss”, i.e., $F_k = 0.03$ means a 3% reduction in annual energy
- Each F_k should be “independent”

F_k are not easy to quantify, e.g., factor for uncertainty in measured GHI (Hansen and Scheiner, 2022)

Perhaps easier than σ_k (prove me wrong)

Bias

E.g., Module rating $F_k = N(0, 0.5)$

Variance

Table 1. SAM Default Distributions for Uncertainty Factors

Factor	Distribution type	Parameters
Irradiance transposition	Normal	$\mu = 11.5, \sigma = 2.5$
Horizon shading	Triangular	min.=-1, mode=0, max.=0
Row shading	Triangular	min.=-5, mode=-1, max.=0
Single module rating at STC	Normal	$\mu = 0, \sigma = 2.0$
Inverter availability	Triangular	min.=-5.7, mode-2.70, max.=0
Spectral response	Normal	$\mu = -1, \sigma = 0.5$
Cell temperature	Normal	$\mu = -2.4, \sigma = 1.0$
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

SAM defaults derived from Reise et al. (2018), IEA-PVPS T13-12:2018

Hansen and Scheiner (2022) doi: 10.1109/PVSC48317.2022.9938853