PARAMETRIC VS MONTE CARLO UNCERTAINTY ANALYSIS FOR DISTINCT U.S. PV LOCATIONS

Comparing methods to assess photovoltaic project risks

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	SOLAR	WIND	BIOMASS	HYDRO-ELECTRIC
GEOTHERMAL	STEAM GENERATING PLANTS	COMBUSTION TURBINE PLANTS	WASTE-TO-ENERGY	NUCLEAR
POWER TRANSMISSION	BIO-REFINING	LNG	GASIFICATION	BESS

CONTEXT AND PURPOSE OF THE UNCERTAINTY COMPARISON

Comparing Uncertainty Methods

The study compares Parametric (normal distribution) approaches and Monte Carlo simulations for energy yield uncertainty in solar projects.

Financial Implications

Energy yield estimates like P50, P90, and P99 directly impact investment, debt sizing, and lender confidence.

Site and Climate Diversity

Analysis includes four U.S. PV sites with varying climates to ensure broad applicability of conclusions.

Purpose and Goal

Aim is to clarify where Parametric methods suffice and where Monte Carlo adds value for robust risk modeling.

MOTIVATION AND PROBLEM STATEMENT IN PV UNCERTAINTY MODELING

Challenge of Conventional Methods

Conventional methods assume independent and linear uncertainties, failing to capture complex interactions in PV systems.

Nonlinear and Correlated Effects

PV performance drivers like degradation and weather exhibit nonlinear, compounding, and correlated behaviors over time.

Impact of Mischaracterized Risk

Inaccurate risk estimates can lead to mispriced projects, inefficient capital, and conservative financing terms.

Need for Advanced Framework

A framework capturing evolving, interacting uncertainties is essential for accurate long-term energy risk modeling.

Challenges with Long-Term Trends

Parametric frameworks often ignore time-dependent degradation and evolving mismatch, causing underestimation of downside risk over long terms.

Implications for Financial Assessment

Understating P90 and P99 outcomes affects debt sizing and covenant margins, highlighting the need for more robust methods.

RATIONALE FOR USING MONTE CARLO SIMULATION

Probabilistic Sampling Approach

Monte Carlo simulation samples from probability distributions to model uncertainty realistically across varied inputs.

Handling Nonlinear Effects

This method captures nonlinear interactions naturally by evaluating system responses over a wide range of inputs.

Capturing Correlations

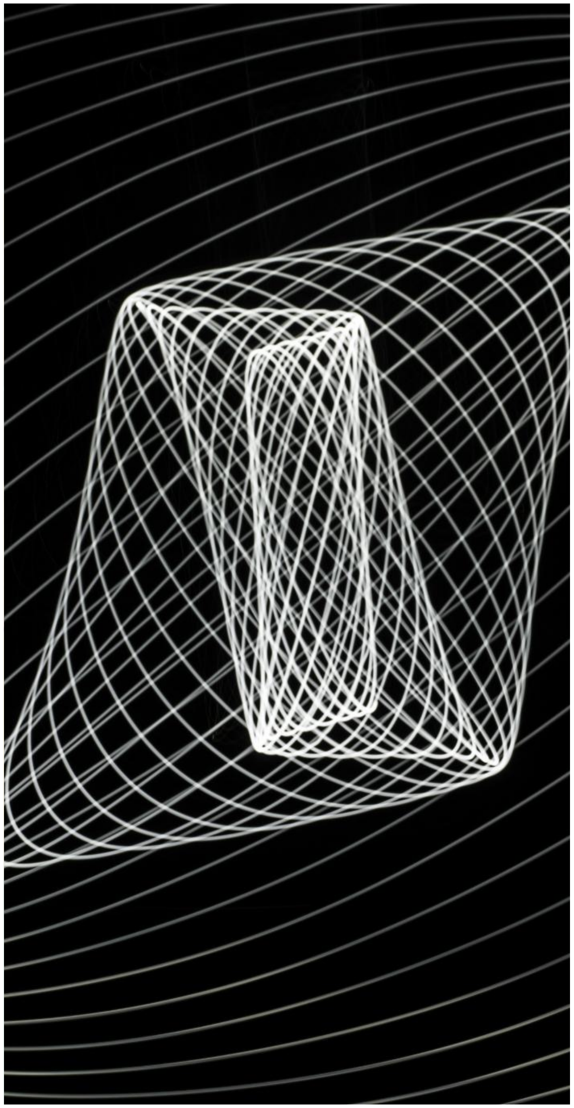
Monte Carlo frameworks explicitly represent correlations between inputs, improving model realism in complex systems.

Risk Distribution Insights

Monte Carlo methods reveal skewness and tail risk, offering deeper understanding beyond standard parametric estimates.

Enhanced Risk Assessment

Thousands of simulations provide richer output distributions, offering a detailed picture of downside risks.



METHODOLOGY AND INPUTS

- Four U.S. locations with different climatic conditions:
  - Hot and Humid
  - Hot and Dry
  - Cold and Humid
  - Cold and Dry

- Consistent equipment, plant design and weather data source

- Harmonized Monte Carlo inputs with the conventional parametric inputs using precise sensitivity analysis

- System Config 325.8 MWp/250 MW
  - JA Solar TopCon Bifacial
  - SMA Sunny Central 4400
  - Single Axis Tracker -/+ 60
  - Axis Height 1.7m, GCR 34.2%
  - System degradation 0.6%

Parametric Inputs[1]	**Value (%)**
Year-to-Year Variability – GHI	**2.0-3.5**
Module Power Distribution	1.2
PV module binning gain	0.2
PV module modelling parameters	1.0
Soiling Uncertainty	0.5
System Degradation	1.2
Mismatch Power loss	0.2
Temperature Model	0.3
Inverter Efficiency	0.5
AC system parameters	0.5
Weather Data Model - GHI	2.4
Total Model Uncertainty	**3.2**

1. Excludes soiling variability, uncertainty related to availability, curtailment, and model biases associated with DNI, Albedo, wind speed, and spectral losses.

RESULTS – P-VALUE RATIOS

- 1-Year downside values consistent, indicating near perfect alignment between Parametric and Monte Carlo inputs
- Material delta noted in the 10-Year and 20-Year Average estimates
- Delta primarily driven by degradation uncertainty and compounding impact of mismatch losses
- Across all four sites, 10-year average p-value ratios are identical for Monte Carlo ⇒ model uncertainty > weather variability

1-Year

P-value	Conventional	Monte Carlo
P75	0.97	0.97
P90	**0.95**	**0.95**
P95	0.93	0.93
P99	0.90	0.91

10-Year Average

P-value	Conventional	Monte Carlo
P75	0.98	0.93
P90	**0.96**	**0.87**
P95	0.95	0.84
P99	0.92	0.77

RESULTS -10YR DOWNSIDES

Hot and Humid

P-value	Conventional	Monte Carlo
P75	0.98	0.93
P90	**0.96**	**0.87**
P95	0.95	0.83
P99	0.92	0.76

Cold and Humid

P-value	Conventional	Monte Carlo
P75	0.98	0.93
P90	**0.96**	**0.87**
P95	0.94	0.84
P99	0.92	0.77

Hot and Dry

P-value	Conventional	Monte Carlo
P75	0.98	0.93
P90	**0.96**	**0.87**
P95	0.95	0.84
P99	0.92	0.77

Cold and Dry

P-value	Conventional	Monte Carlo
P75	0.98	0.93
P90	**0.96**	**0.87**
P95	0.95	0.84
P99	0.92	0.79

RESULTS -20YR DOWNSIDES

Hot and Humid

P-value	Conventional	Monte Carlo
P75	0.98	0.85
P90	**0.96**	**0.71**
P95	0.95	0.63
P99	0.92	0.48

Cold and Humid

P-value	Conventional	Monte Carlo
P75	0.98	0.84
P90	**0.96**	**0.70**
P95	0.94	0.61
P99	0.92	0.45

Hot and Dry

P-value	Conventional	Monte Carlo
P75	0.98	0.84
P90	**0.96**	**0.70**
P95	0.95	0.62
P99	0.92	0.48

Cold and Dry

P-value	Conventional	Monte Carlo
P75	0.98	0.84
P90	**0.96**	**0.70**
P95	0.95	0.62
P99	0.92	0.46

IMPACT ON ENERGY YIELD & FINANCING

- **1-year** downside p-values ratios are effectively identical between parametric and Monte Carlo under harmonized inputs, so near-term lender cases are largely **unaffected** by the method choice.
- Over **10-year averages and 20-year averages**, Monte Carlo yields meaningfully lower P90/P50 than the parametric method, signaling a **material reduction** in bankable long-term energy for the same project.
- However, if we implement the **Maximum Likelihood Estimation Plane Of Array** method for weather selection, that will tighten the P90/P50 ratio.
- The long-tenor gap is driven mainly by **degradation and degradation uncertainty** rather than weather variability, so financing negotiations and mitigations should target long-term asset health.
- How can we get more certainty on degradation and degradation uncertainty?
  - Sharing of performance data by asset owners and perform an AI-drive data analysis
  - Better contracting/warranty terms

THANK YOU!

For additional information regarding this presentation, or E3's solar services, please reach out to:

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