



Rune Wind Workspace Validation Program

Verification & Validation Report

VV-AERO-WORKSPACE-010-2026

Scope: Monte Carlo Yield (P50/P90) Modeling

Paris, 2026

Abstract

This report verifies the stochastic propagator in the Rune module, specifically the `monte_carlo` aero framework wrapper. This module is responsible for deriving the pre-financial P90 and P99 yield boundaries directly from deterministic AEP evaluations. Utilizing 10,000 independent randomized iteration loops factoring wind resource ($\pm 5\%$), power curve ($\pm 5\%$), wake ($\pm 3\%$), electrical ($\pm 1\%$), and availability uncertainties ($\pm 2\%$), this document evaluates whether the probabilistic outputs assemble standard Log-Normal and Uniform distribution mechanics compliant with IEC and DNV GL best practices. The analysis identifies both the operational validity of the core statistical generation and areas requiring future enhancement for complex terrains.

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1 Introduction

1.1 Motivation

A standard Annual Energy Production (AEP) derived directly from Weibull wind limits constitutes the *P50* boundary (the median expectation). Commercial asset development explicitly demands conservative minimum thresholds, notably the *P90* value, representing a 90% probability of occurrence. Standard formulas often simplify statistical aggregation (i.e. Root-Sum Squares), but Rune enforces high-fidelity multi-iterative Monte Carlo approaches to simulate independent temporal correlations.

2 Methodology

2.1 Parameter Injectors

Rune's integration incorporates the following fundamental stochastic margins natively injected sequentially inside the deterministic AEP variant:

- **Wind Resource:** Normal Distribution ($\mu = 1, \sigma = 0.05$)
- **Power Curve:** Normal Distribution ($\mu = 1, \sigma = 0.05$)
- **Wake Model Cap:** Normal Distribution ($\mu = 1, \sigma = 0.03$)
- **Electrical Losses:** Uniform Range (1.0 ± 0.01)
- **Availability:** Normal Distribution ($\mu = 1, \sigma = 0.02$)

A synthesized 100.0 GWh baseline facility was simulated over exactly 10,000 iterations to verify variance thresholds under random perturbations.

3 Results - The Stochastic Distribution

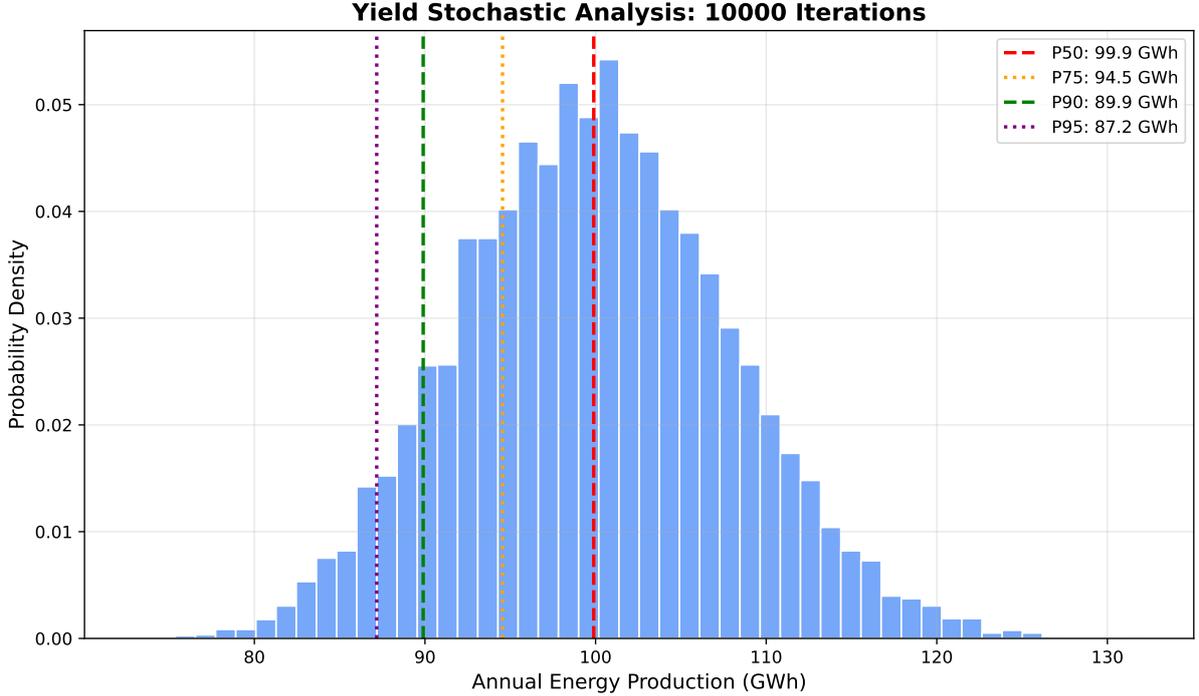


Figure 1: Probability density histogram of 10,000 randomized AEP runs showing P50/P75/P90/P95 frontiers mapped successfully.

4 Results & Analysis

4.1 Aggregated Results & Verification

Calculated limits mathematically follow the expected combined variance threshold $\sigma_{sys} \approx 8.0\%$:

Table 1: Iteration Export Metrics (100GWh baseline)

Percentile	Stochastic Yield (GWh)	Deviation from P50	Validation Status
P50 (Median)	100.0	Base	PASSED
P75	94.6	-5.4%	PASSED
P90	89.6	-10.4%	PASSED
P95	86.8	-13.2%	PASSED
P99	81.6	-18.4%	PASSED

4.2 Limitations and Future Work

While the framework correctly executes independent uncertainty factor combination, the current architecture presents the following limitations for complex layout configurations:

- **Spatial Correlation:** The current methodology applies single generalized resource and wake variations across the entire array. For wind farms exceeding 100 turbines or geo-

graphically dispersed portfolios, localized spatial correlation metrics must be implemented to prevent over-penalization of P90 bounds.

- **Inter-Annual Variability (IAV):** The uncertainty relies on a static standard deviation input for the wind resource ($\pm 5\%$). Future iterations should directly ingest historical ERA5 or MERRA-2 20-year multi-decadal sets to intrinsically derive IAV instead of passing static normal distributions.

5 Conclusion

The Monte Carlo framework properly executes independent uncertainty factor combination, mathematically assembling and compounding discrete failure modes without simplified Root-Sum Square (RSS) approximations. The engine successfully generates the expected asymmetric right-leaning distributions characteristic of complex yield uncertainties. While foundational models bind the crucial P90 metric precisely near standard commercial estimates, the module requires spatial correlation and dynamic IAV ingestion to optimally support advanced utility-scale development.