Impact of PV Module Degradation Rate on Utility Scale Systems

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Outline

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- LCOE
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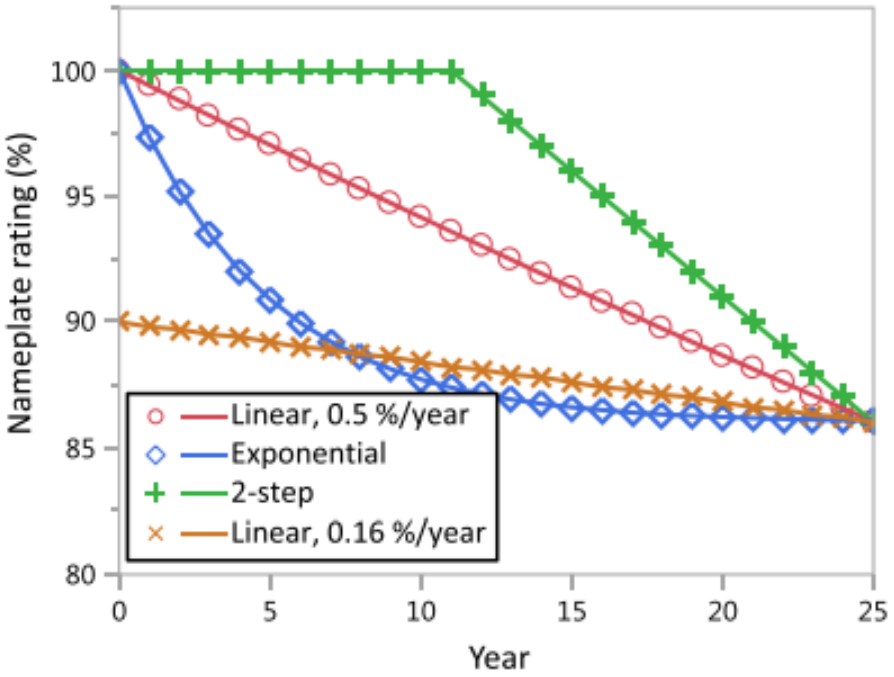
Motivation

Question: What impact does module degradation have on system degradation and thus energy cost in utility-scale PV systems?

Factor #1:

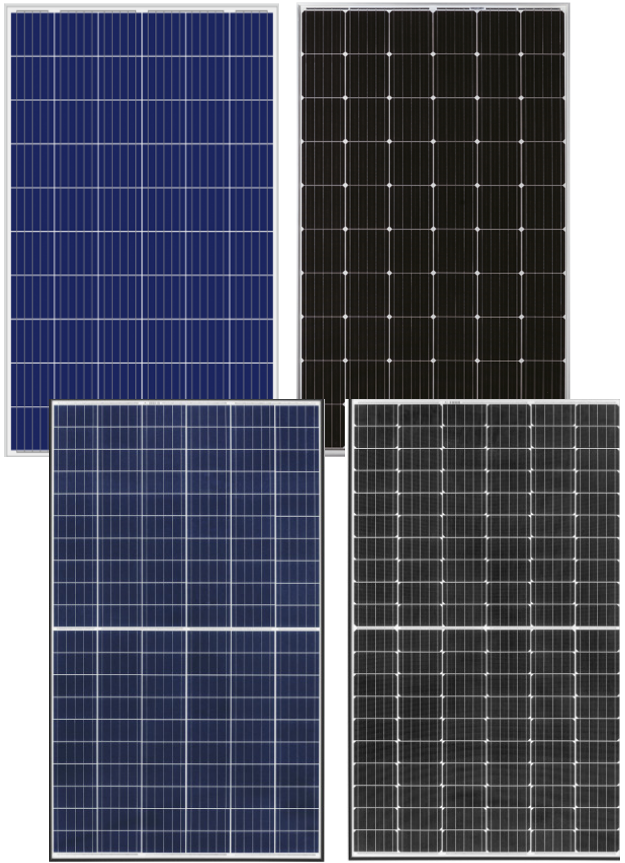
Degradation Study

Jordan, et al. "Compendium of Photovoltaic Degradation Rates", PIPV 2016



Factor #2:

Module Technology



Factor #3:

Building Successful Projects

- Bidding
- Financing
- PPA

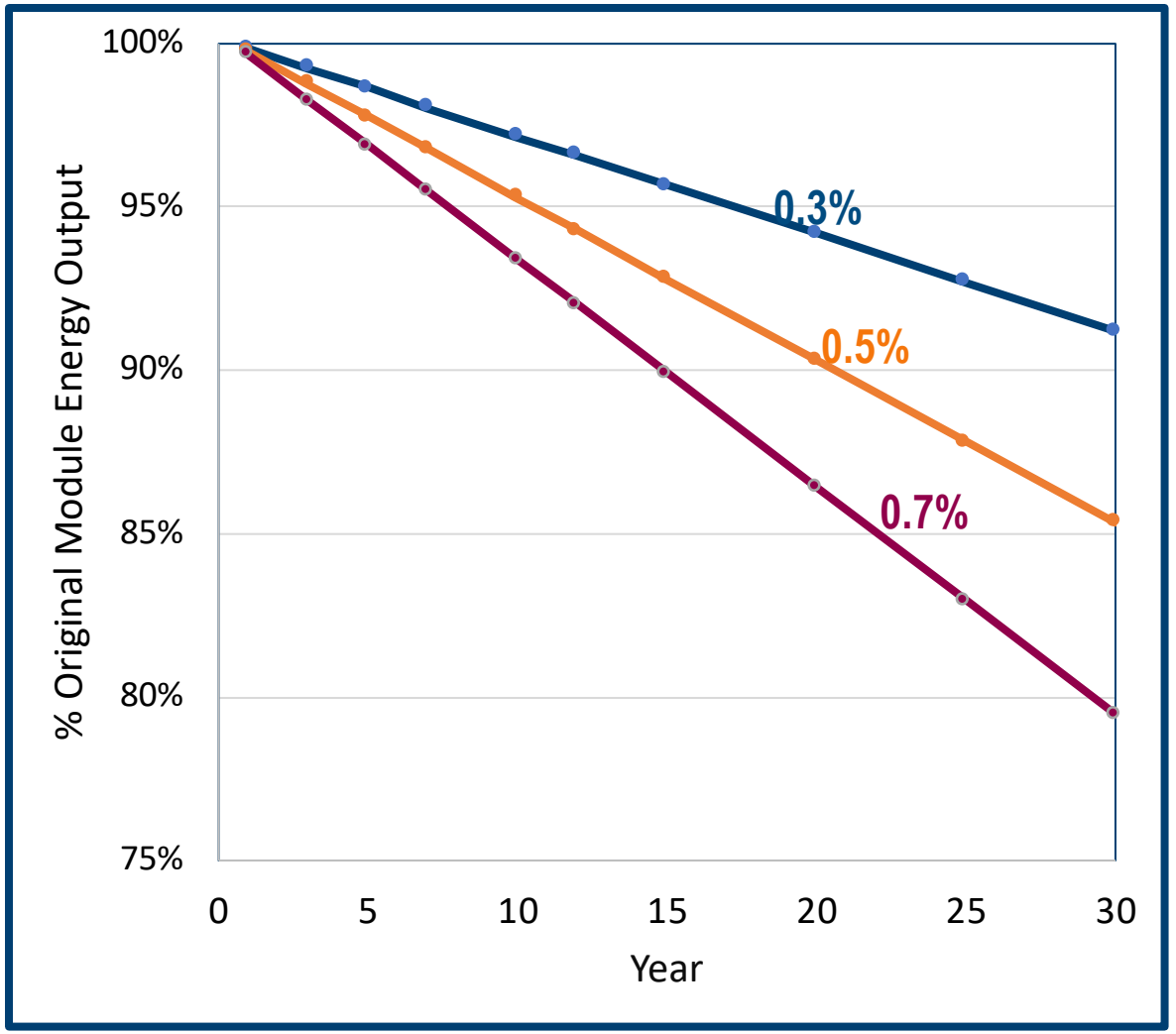
Methodology

Model 100MW, single axis tracking, utility PV systems in PVSyst, varying irradiance, degradation rate and DC-AC power ratio

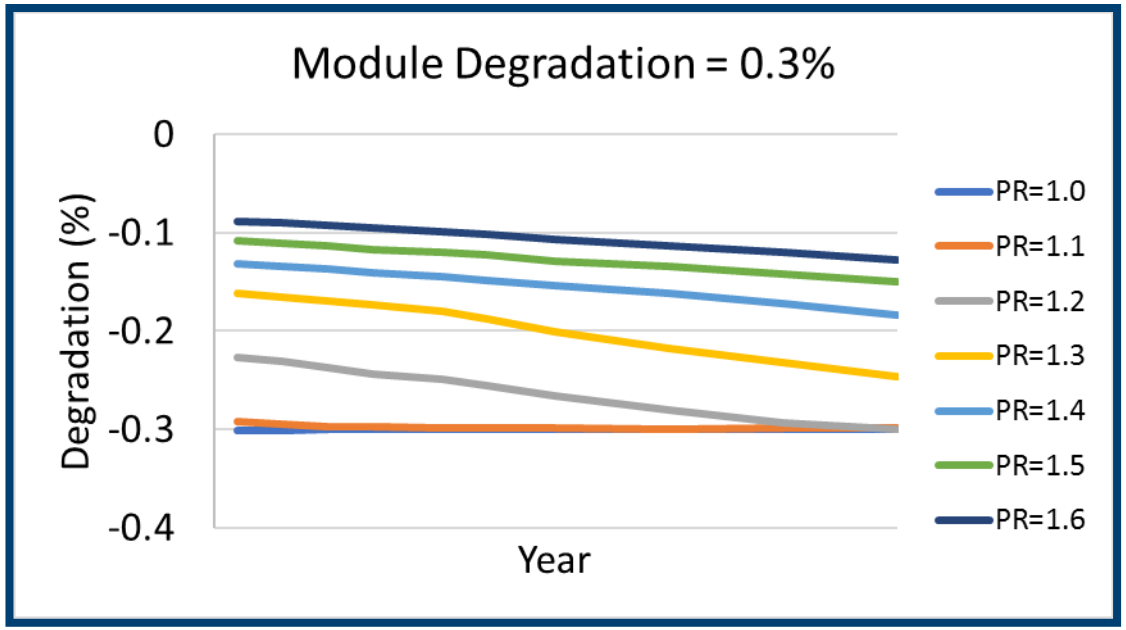
- 3 sites (high, medium, low irradiance)
- 3 annual degradation rates for modules (0.3%, 0.5%, 0.7%)
- 7 power DC-AC ratios (1:1.6)

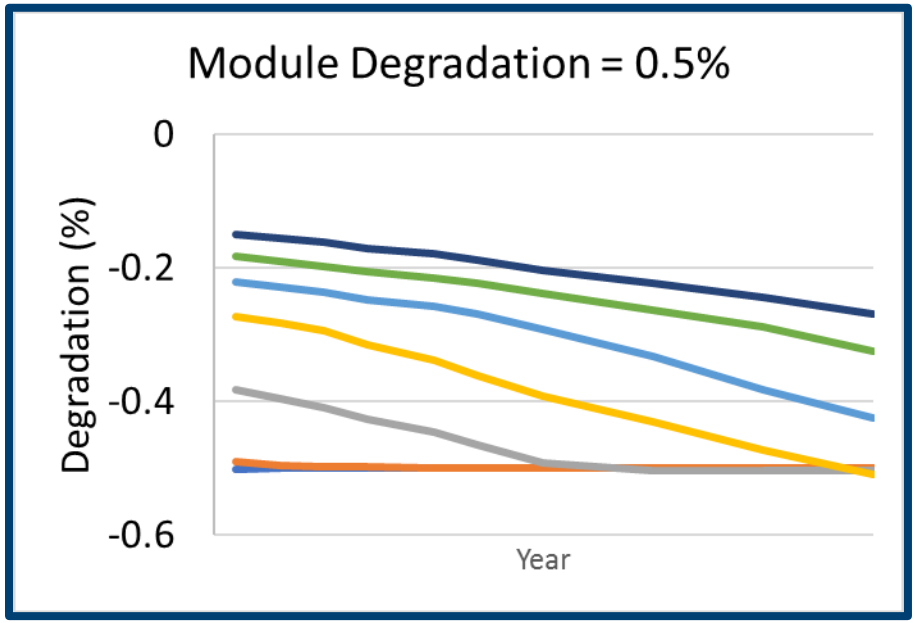
Calculate and compare simple LCOE for systems with various module degradation (linear and nonlinear)

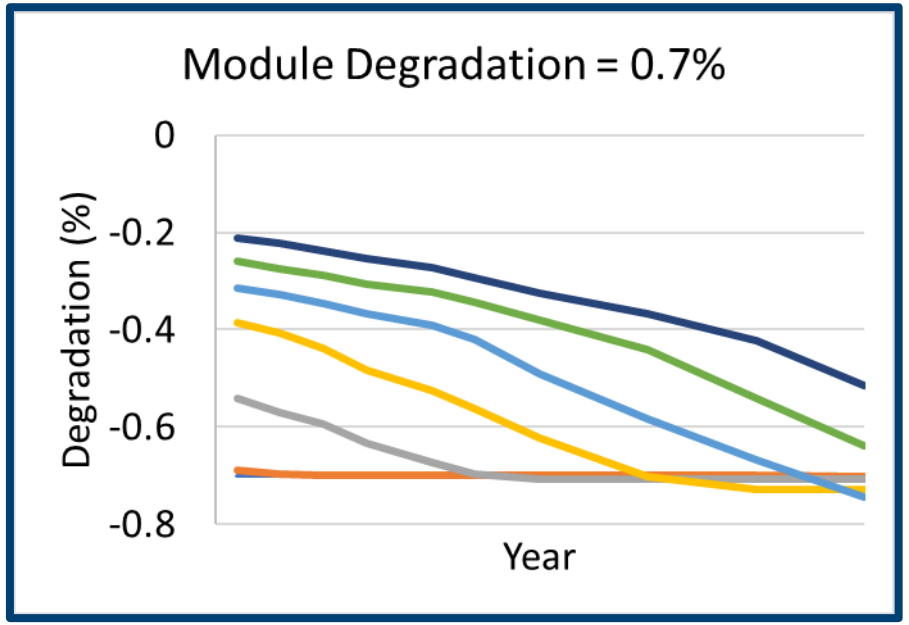
Linear Module Degradation



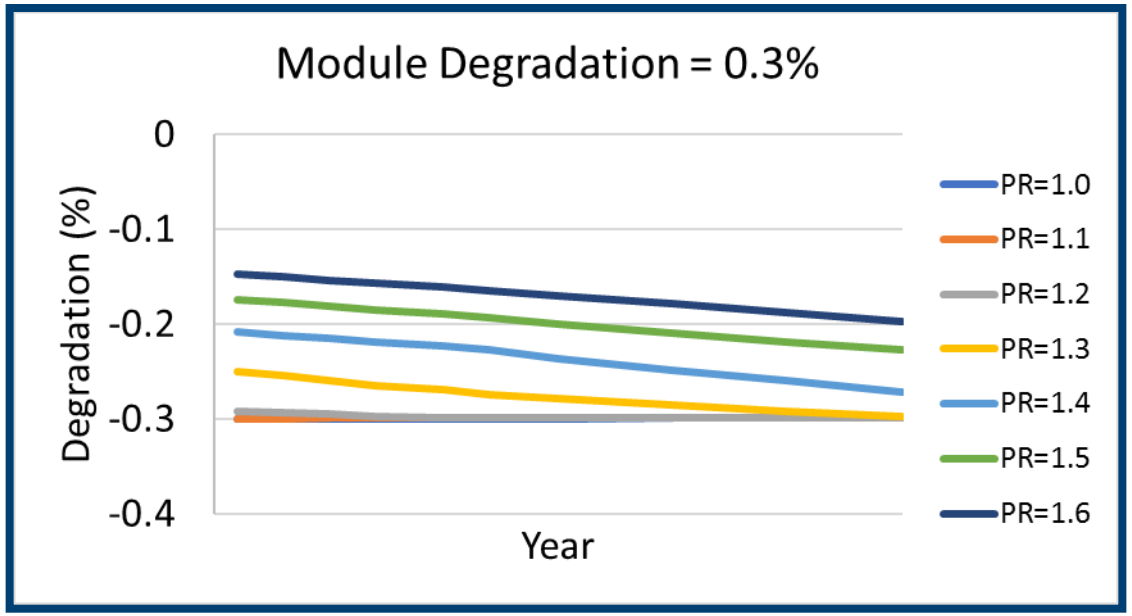
Annual System Degradation Over Project Lifetime: High Irradiance

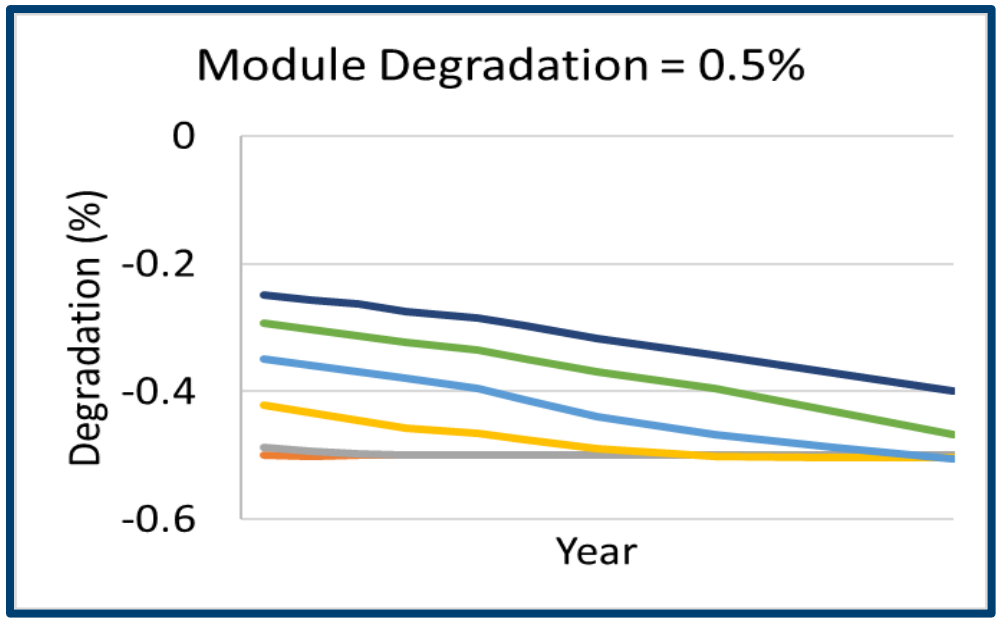


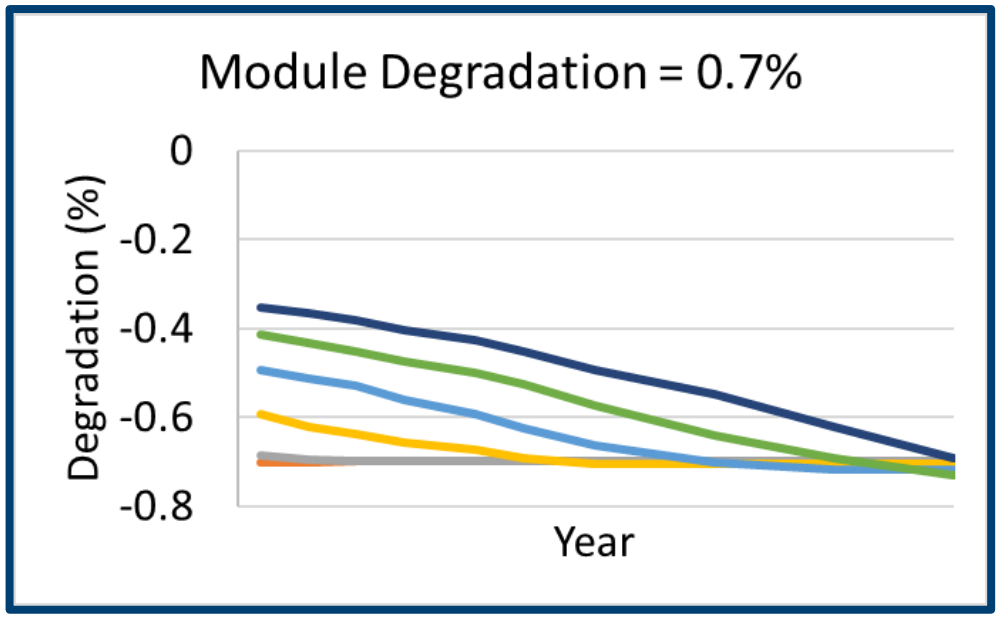




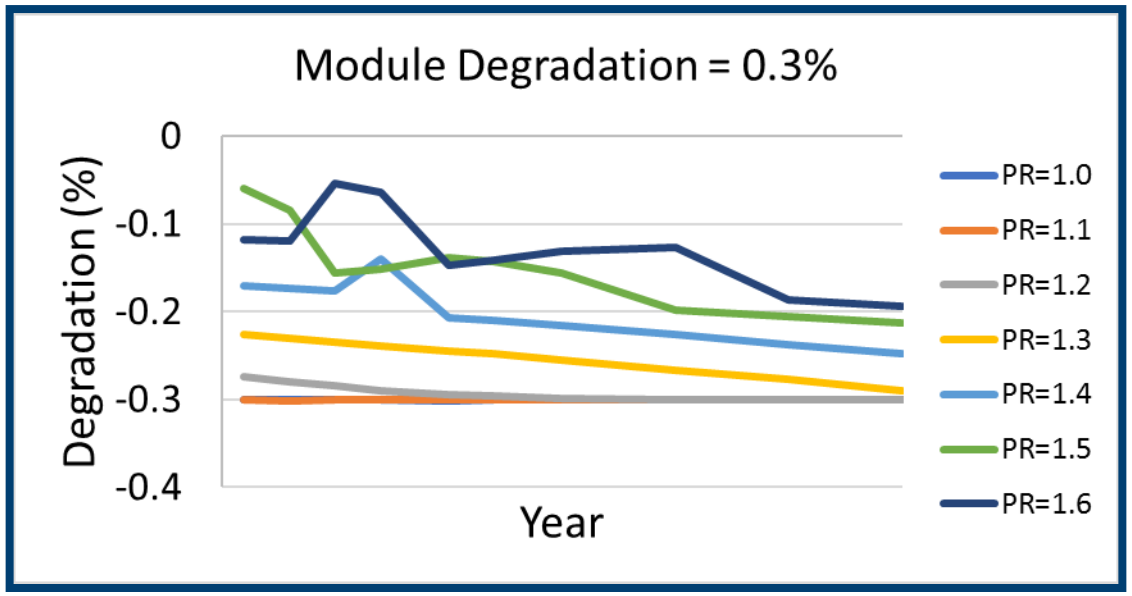
Annual System Degradation Over Project Lifetime: Medium Irradiance

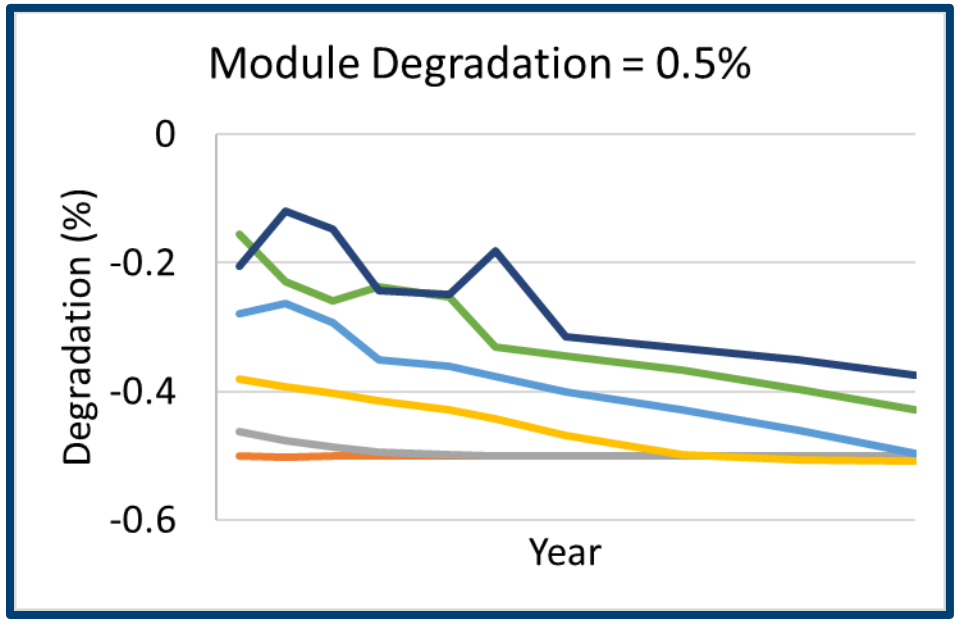


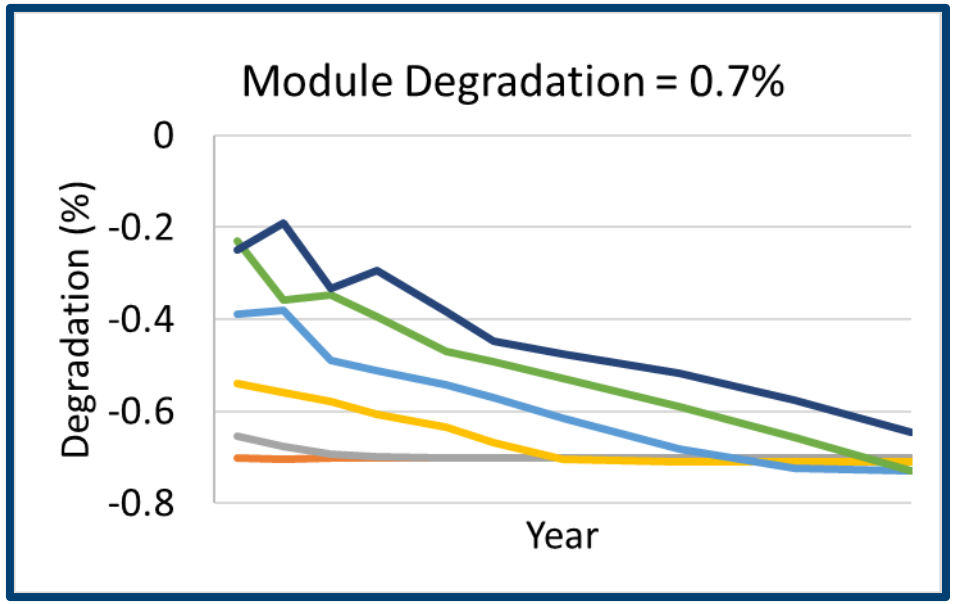




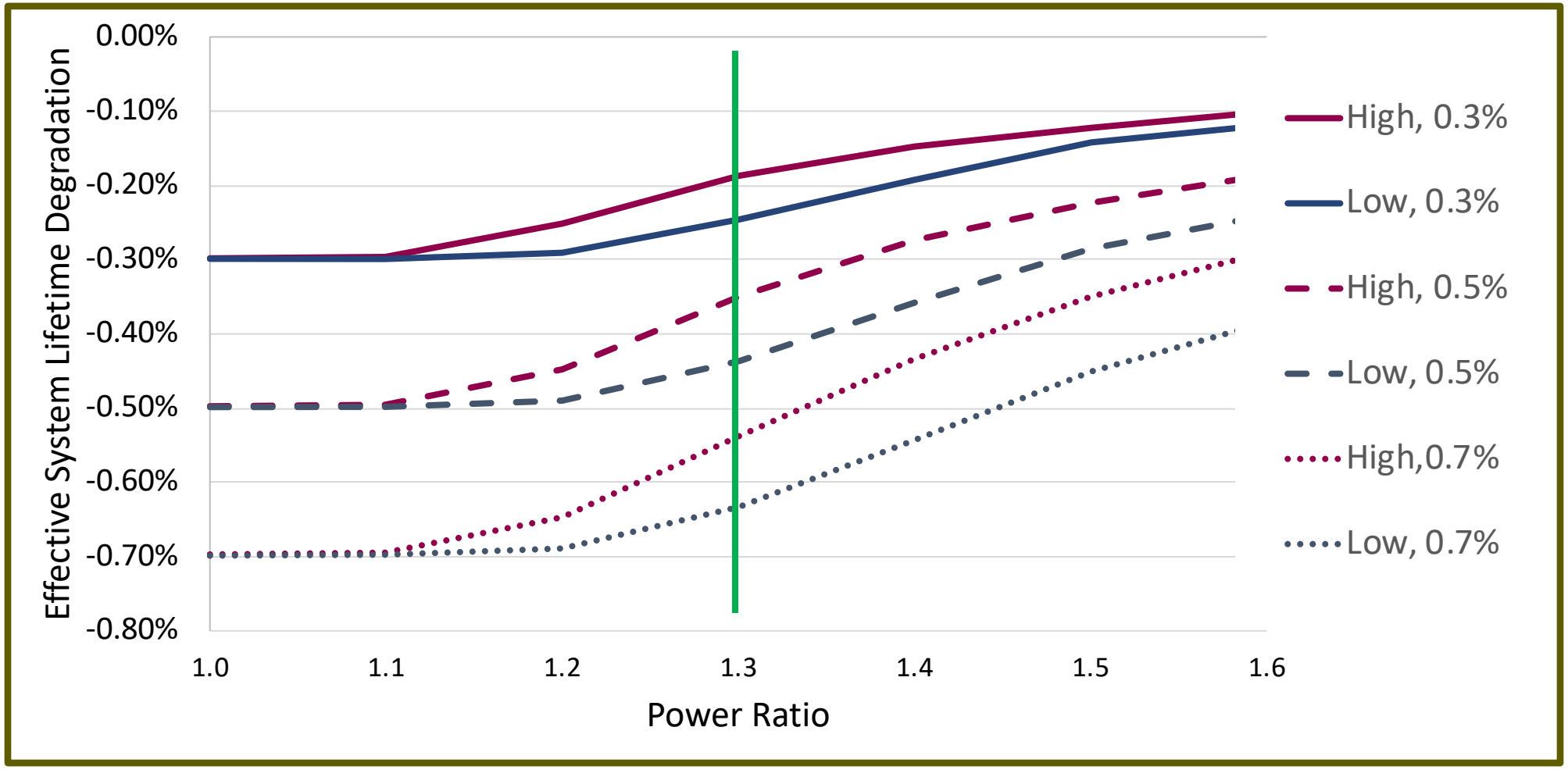
Annual System Degradation Over Project Lifetime: Low Irradiance







Equivalent Linear Lifetime Degradation



LCOE Calculation

$$LCOE = \frac{Total\ Lifecycle\ Cost}{Total\ Lifetime\ Energy\ Production}$$

$$= \frac{Initial\ Cost + \sum_{n=1}^{N} \frac{O\&M*(1-TaxRate)}{(1+r)^n}}{\sum_{n=1}^{N} Initial\ Production * \frac{(1-R_D)^n}{(1+r)^n}}$$

Parameter	Value
Initial Cost	$1.125- $1.15/Wdc
O&M	$14/kW/yr
Tax Rate	30%
Discount Rate	7.50%
System Lifetime	30 years

LCOE – Linear Module Degradation

High Irradiance Site

LCOE (¢/kWh)

	Annual Module Degradation Rate			Percent LCOE difference	
DC-AC Ratio	0.3%	0.5%	0.7%	0.3% vs. 0.5%	0.7% vs. 0.5%
1	4.27	4.36	4.46	-2.0%	2.1%
1.3	4.37	4.44	4.51	-1.4%	1.7%
1.6	4.90	4.94	4.98	-0.8%	0.9%

Low Irradiance Site

LCOE (¢/kWh)

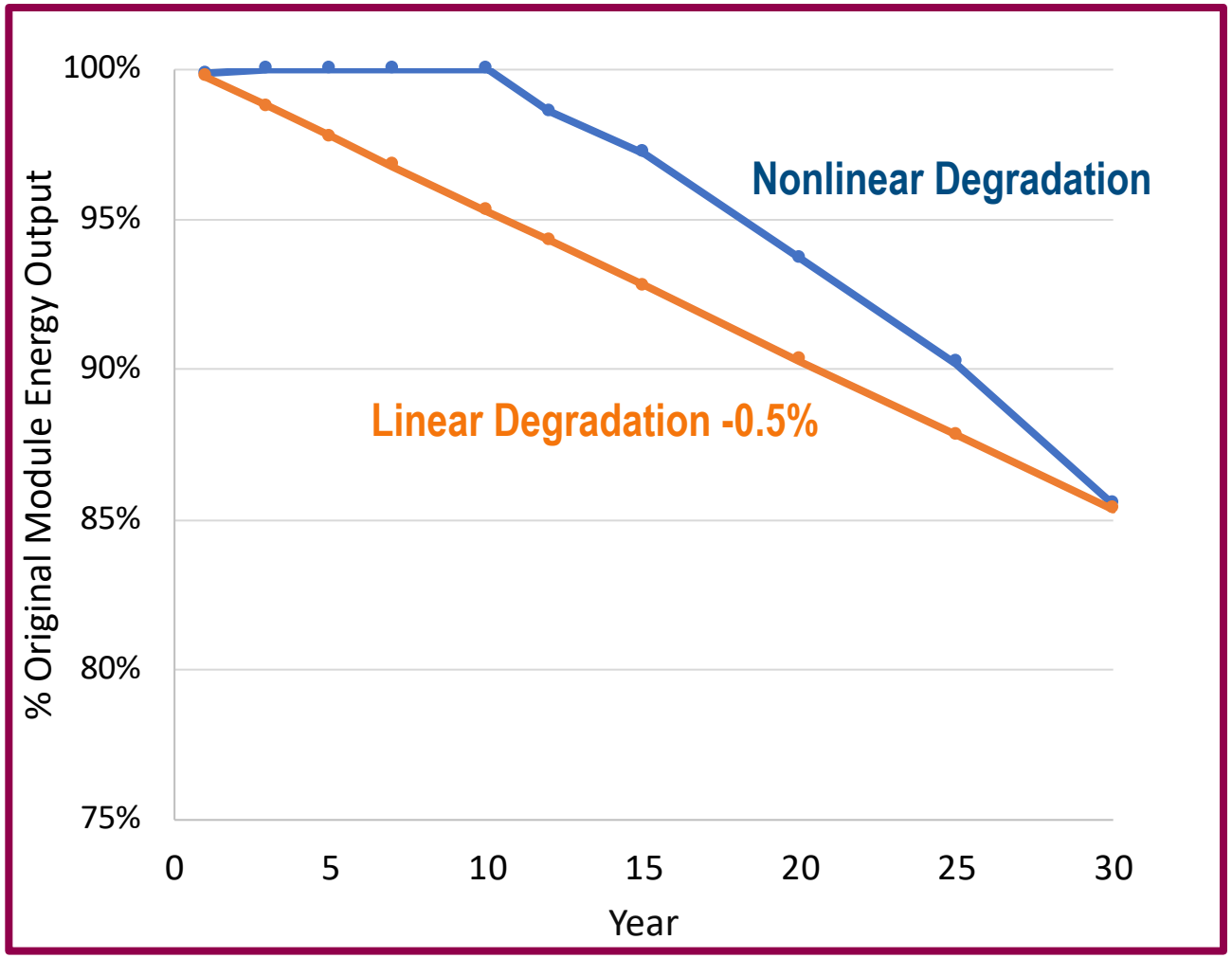
	Annual Module Degradation Rate			Percent LCOE difference	
DC-AC Ratio	0.3%	0.5%	0.7%	0.3% vs. 0.5%	0.7% vs. 0.5%
1	6.58	6.72	6.86	-2.0%	2.1%
1.3	6.59	6.71	6.84	-1.8%	2.0%
1.6	7.13	7.20	7.29	-1.0%	1.2%

- LCOE changes by ~4% when annual module degradation increases from 0.3% to 0.7%
- Clipping masks degradation more with high irradiance

Nonlinear Module Degradation

Baseline 0.5% linear module degradation (high irradiance site)

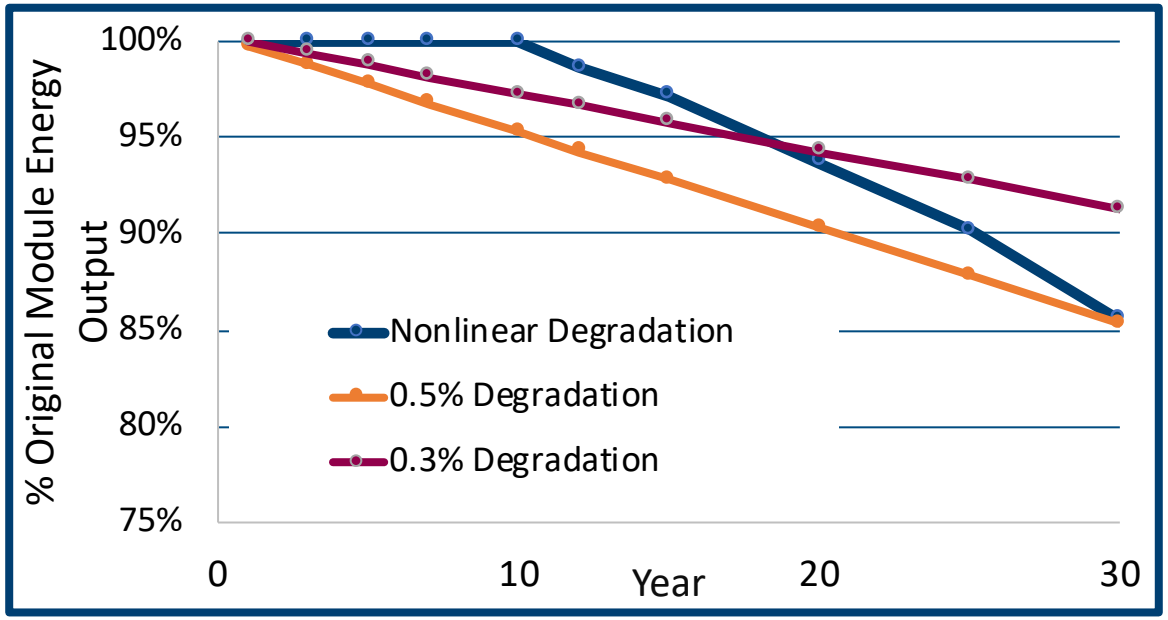
Nonlinear Degradation is zero for first 9 years, 0.7% annually in subsequent years



LCOE – Nonlinear Module Degradation

LCOE (¢/kWh)

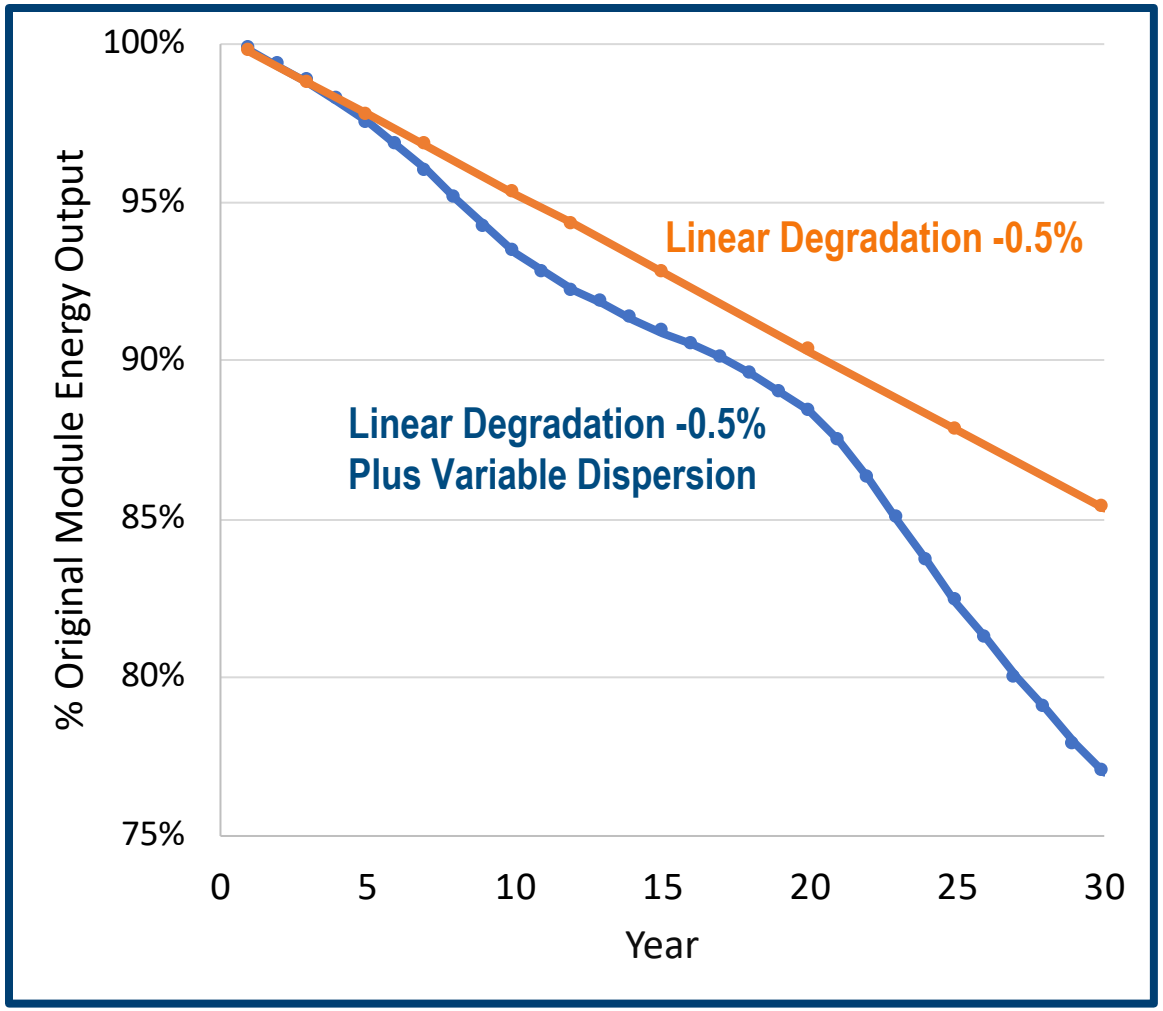
	Annual Module Degradation Rate		Percent LCOE Difference
DC-AC Ratio	0.5% Linear	Nonlinear	0.5% Linear vs. Nonlinear
1	4.36	4.27	-2.0%
1.3	4.44	4.38	-1.3%
1.6	4.94	4.91	-0.7%



Variable Module Degradation

Baseline 0.5% linear module degradation (high irradiance site)

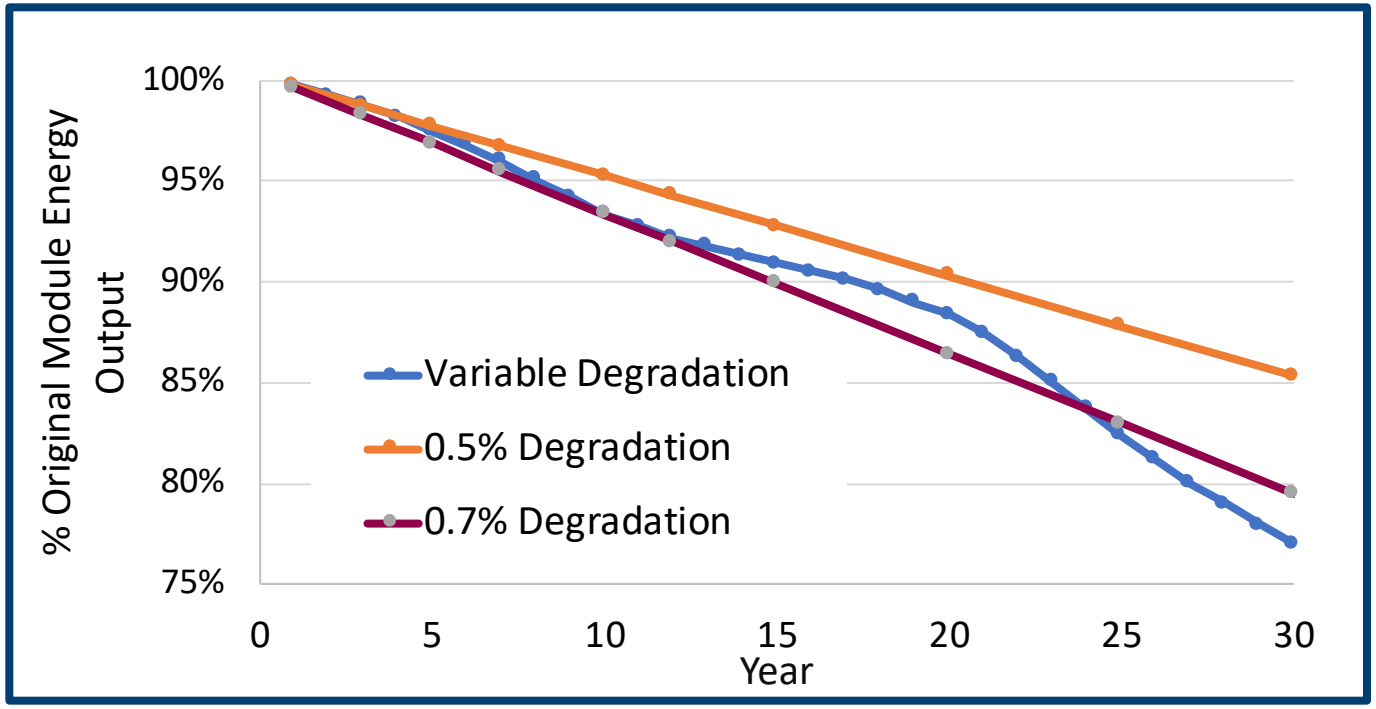
Add mismatch losses due to variable degradation: PVSyst Isc and Voc Dispersion - RMS 0.4% per year (default)



LCOE – Variable Module Degradation

LCOE (¢/kWh)

DC-AC Ratio	Annual Module Degradation Rate		Percent LCOE Difference
	0.5% Linear	Variable Distribution	0.5% vs. Variable
1	4.36	4.43	1.5%
1.3	4.44	4.49	1.2%
1.6	4.94	4.97	0.6%



Summary

PV module level degradation is greater than its resulting system level degradation in single axis tracking installations with a greater-than-unity DC-AC ratio – depends on site irradiance.

Clipping can cause nonlinear variation in annual PV system degradation rates.

PV system LCOE is affected significantly by both linear and nonlinear module degradation rates and patterns even when masked by clipping.

Effect of variable module degradation on system level degradation should be further explored.


Thank you!