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Probabilistic Performance and Cost Modeling for Concentrating Solar Power Plants

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Overview

- Introduction
- Probabilistic Modeling Approach
- Probabilistic Modeling Examples in CSP
- Summary

Introduction

- **Performance and cost models have typically used deterministic models**
  - No quantification of uncertainty and confidence
  - Sensitivity (one-off) analyses provides limited insight
- **Probabilistic modeling**
  - Quantification of uncertainties and likelihood of achieving cost and performance metrics
  - Identification and ranking of the most important parameters and processes

Previous Work

- **Becker and Klimas (eds.), 1993**
  - Probabilistic power tower and cost model
  - Annual insolation not varied
  - Low number of realizations

- **Ho and Kolb (ASME ES2009, JSEE 2011)**
  - Probabilistic power tower and cost model
  - Annual insolation not varied
  - SOLERGY run manually

- **Ho et al. (SolarPACES 2009, Solar Energy 2011)**
  - Probabilistic power tower performance model
  - SOLERGY runs automated in batch mode with LHS inputs
  - Annual insolation varied using 30-year data

Previous Work

- **Ho and Dobos (SolarPACES 2010)**
  - Implementation of probabilistic methods in System Advisor Model (SAM)
  - Parabolic trough performance and cost model
  - Annual insolation varied using 30-year data
- **Finch and Ho (SolarPACES 2011)**
  - Applied stochastic SAM model to power tower
  - Evaluated impact of technology improvement opportunities (TIOs) on levelized cost of electricity

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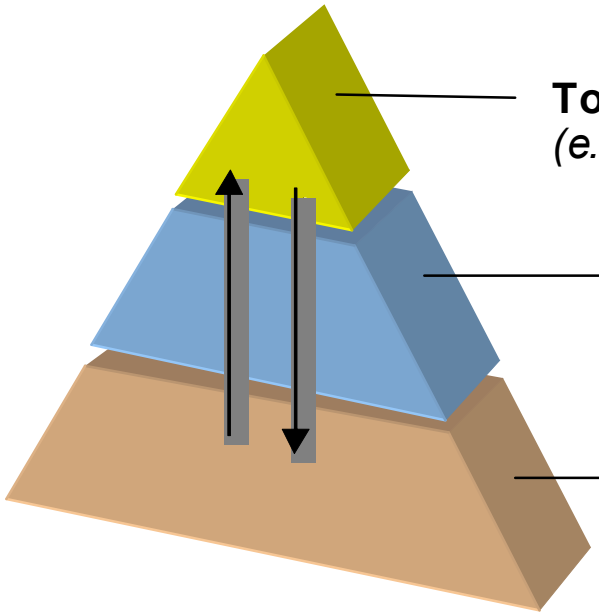
Total System Modeling Pyramid



Total system models – performance and cost
(e.g., SAM, SOLERGY)

Component and process models
(e.g., collector/reflector optics, receiver performance, thermal storage processes, power output)

Input parameters and distributions
(e.g., geometry, reflectivity, solar radiation, temperature, flow rates, efficiencies, costs)

Need to honor uncertainties in component and process models to improve reliability of total-system models

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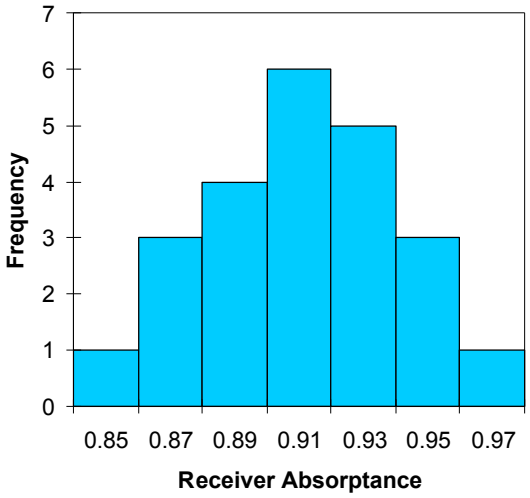
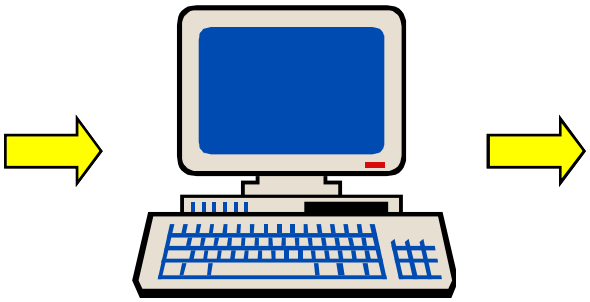
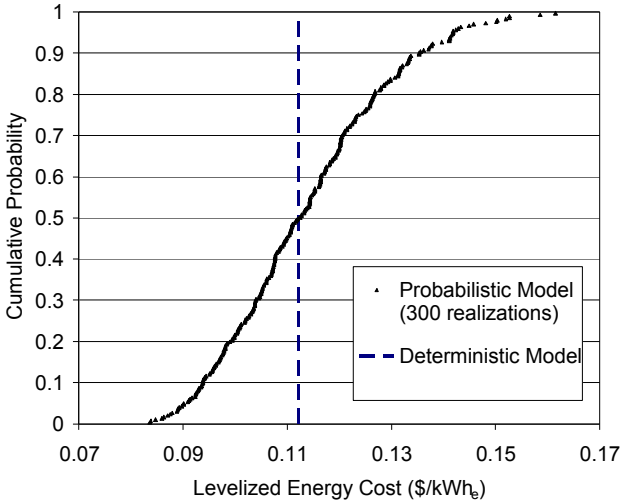
Probabilistic Modeling







Stochastic Inputs
(Latin Hypercube Sampling)

Multiple Computer Simulations
(e.g., SOLERGY, SAM)

Distribution of Results
(Multiple Simulations)

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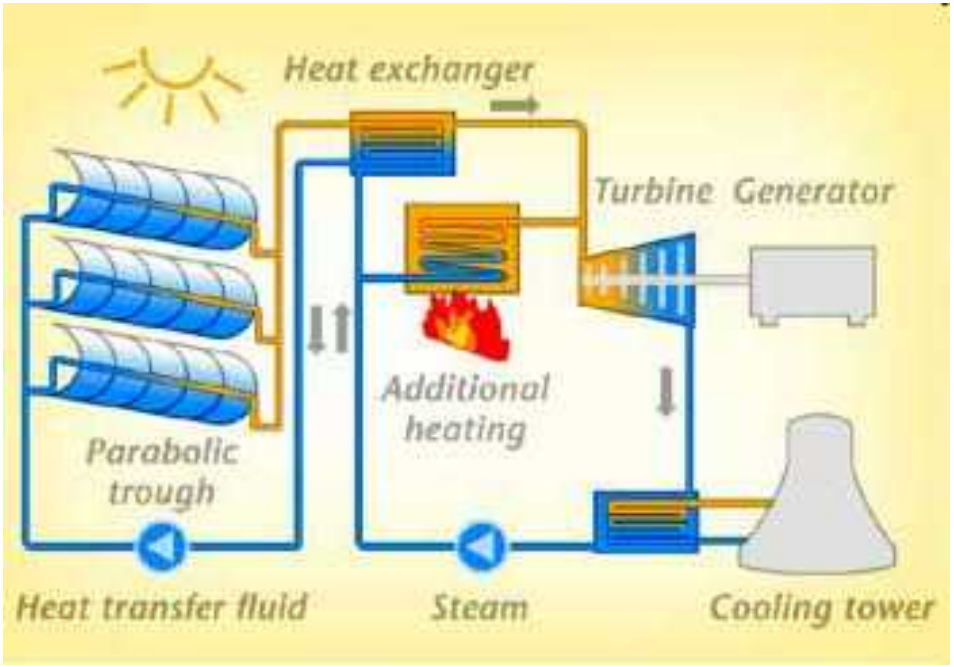
Parabolic Trough Example
(Ho and Dobos, 2010)

- **64 MW_e Parabolic Trough Plant (e.g., Nevada Solar One)**
  - 30-year plant life
  - No explicit storage
  - Eleven parameters chosen for uncertainty analysis



Uncertainty Distributions for Input Parameters

Parameter	Nominal Value	Distribution
Mirror Reflectance	0.935	Uniform, 0.91 - 0.96
Receiver Absorptance	0.96	Uniform, 0.93 - 0.97
Fraction of Broken Glass Receivers	0.01	Uniform, 0.01 - 0.15
Power Block Startup Time	0.5 hour	Normal, Mean = 0.5 std. dev. = 0.2
Overall System Availability	96 %	Uniform, 88 - 96
Fixed Parasitic Load	0.0055 %	Uniform, 0.003 - 0.01
Total Annual Insolation	2.62 MWh/m^2	User Defined CDF
Real Discount Rate	8.0 %	Uniform, 5.5 - 8.5
Inflation Rate	2.5 %	Uniform, 1.5 - 3.5
Fixed O&M Cost per Year	80 $/kW (nameplate capacity)	Uniform, 70 - 100
Engineering, Procurement, Construction	15 % (of direct cost)	Uniform, 15% - 20%

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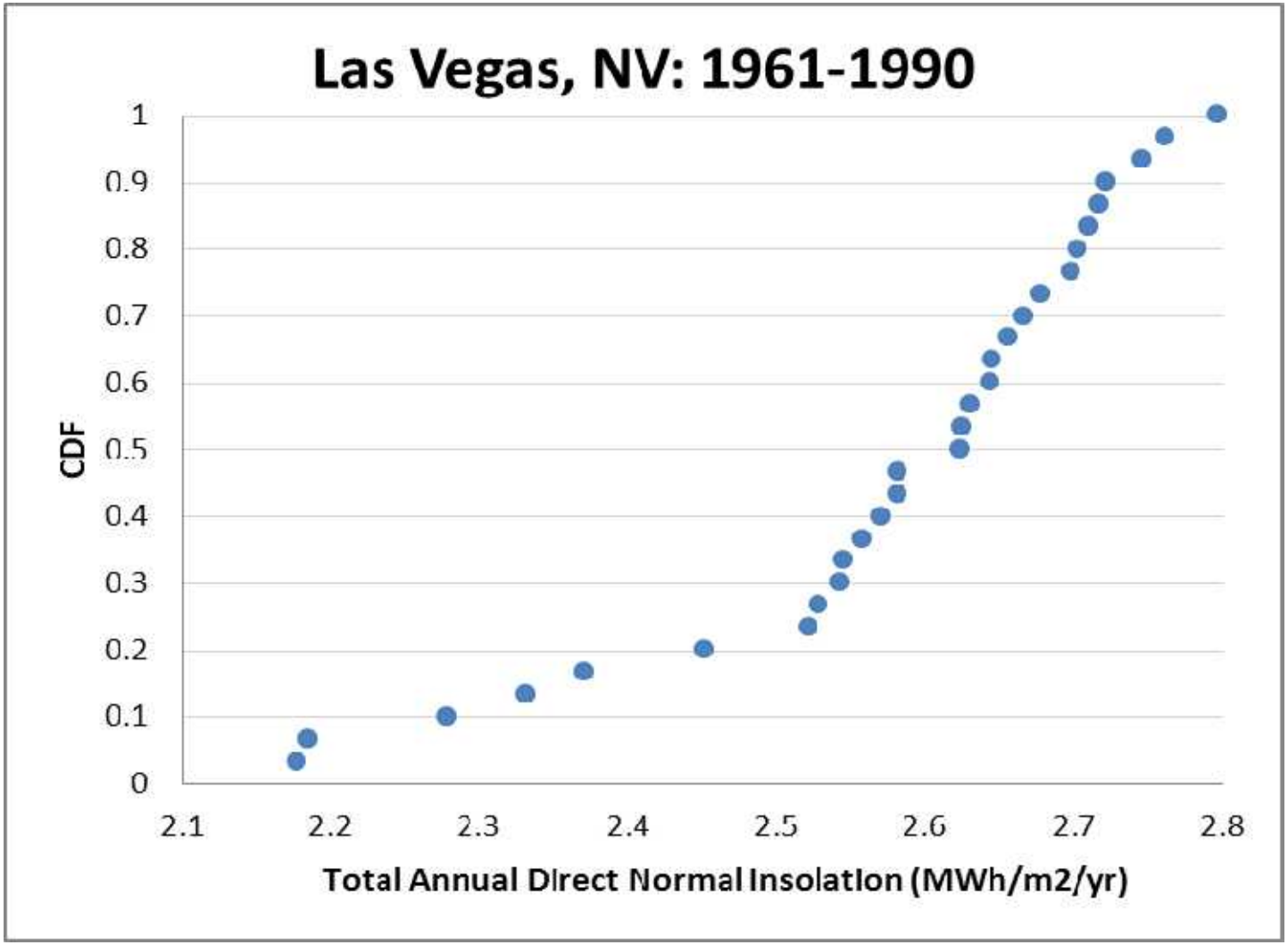
Insolation Uncertainty
(Cumulative Distribution Function for 30 years)



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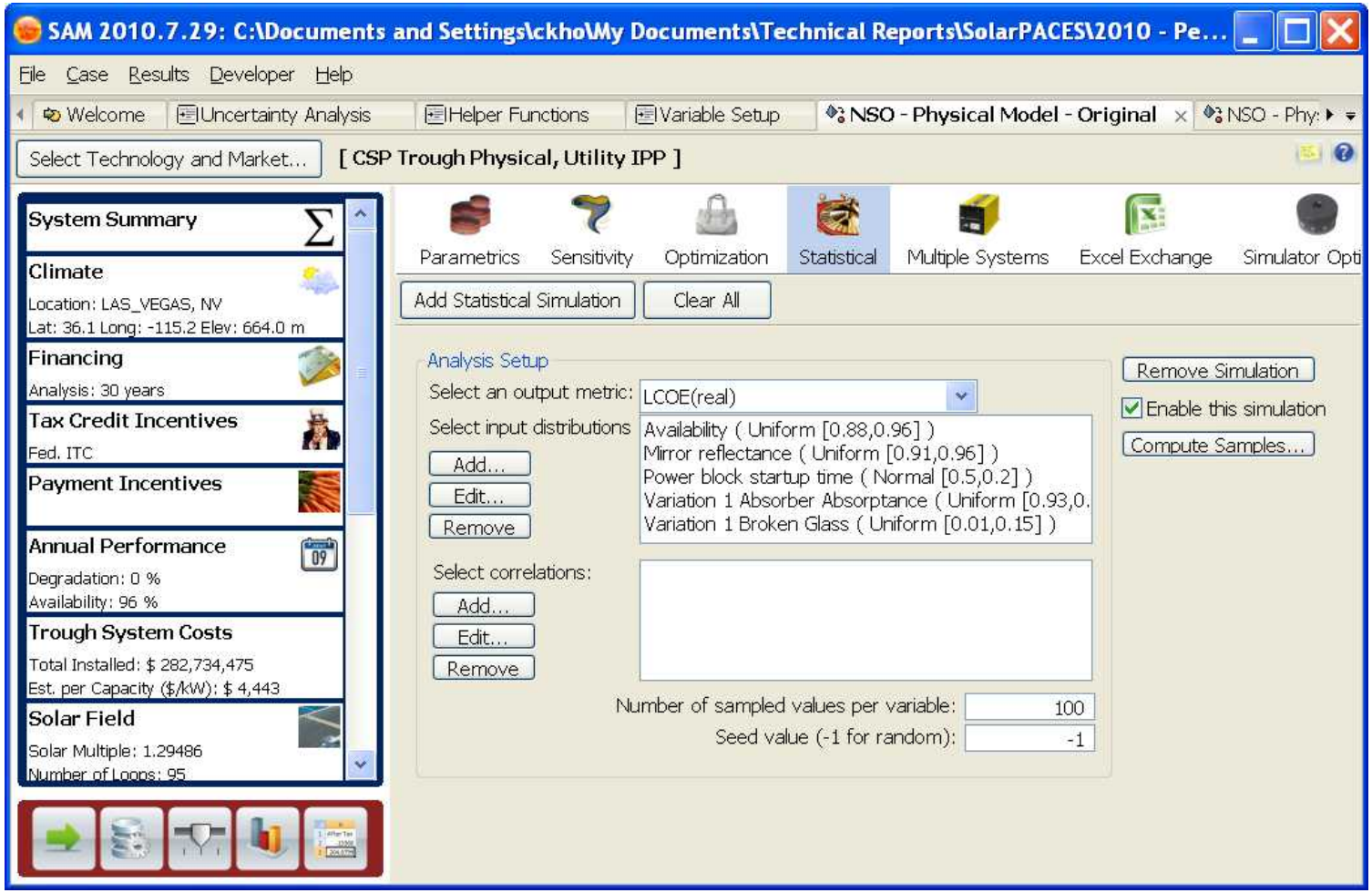
Stochastic Sampling
(Latin Hypercube Sampling)



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Stochastic Sampling

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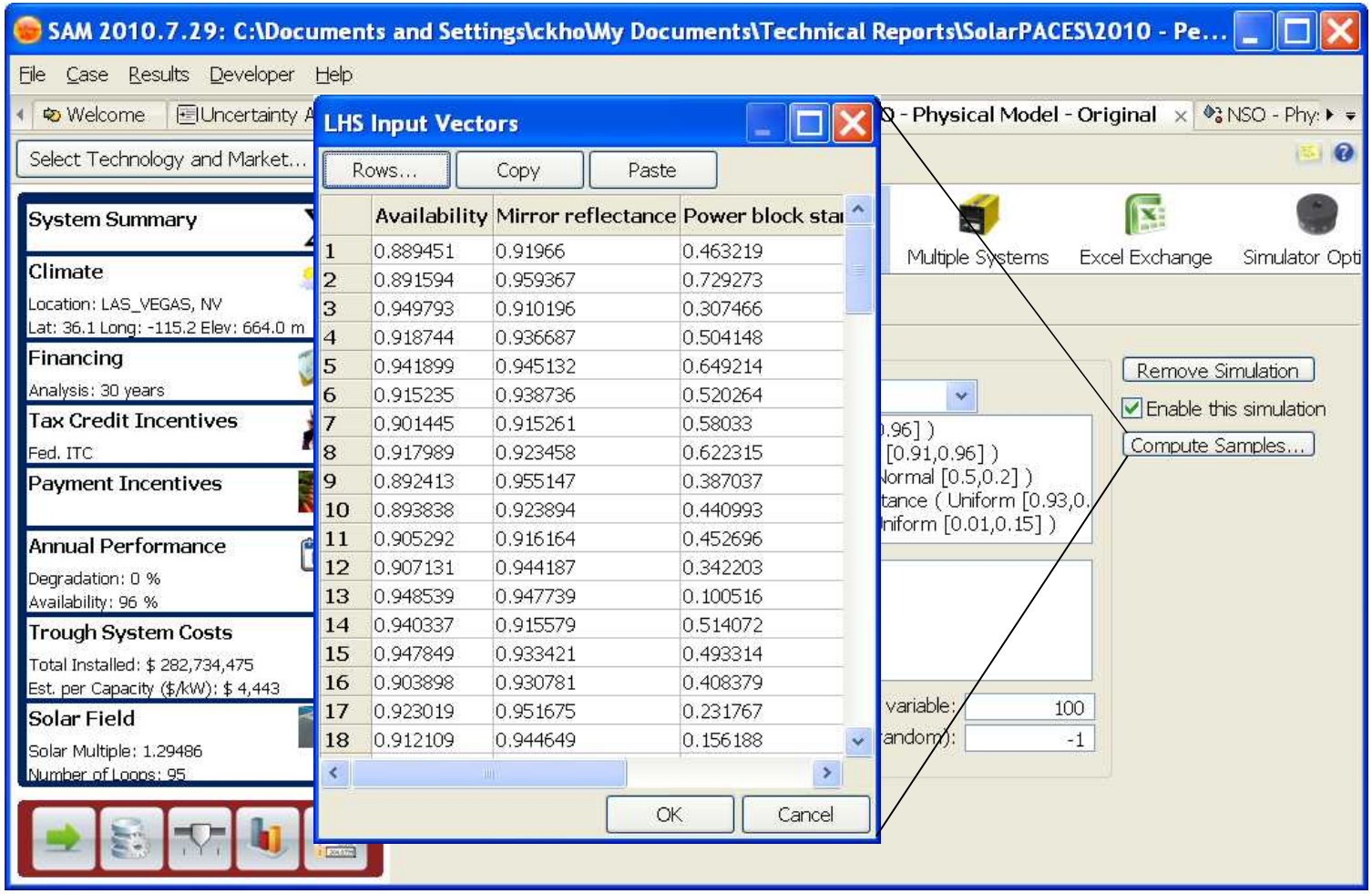

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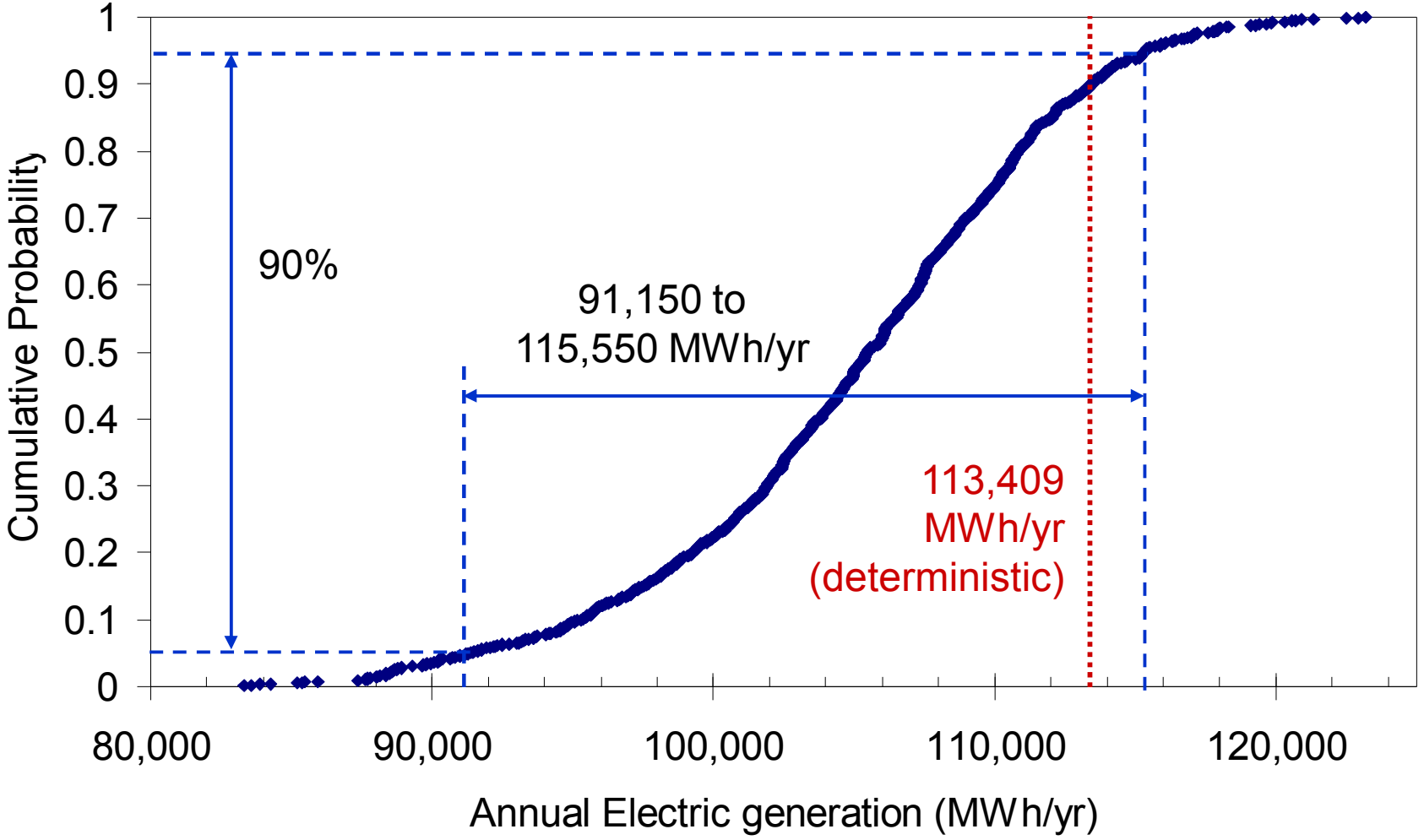
Results
(1000 realizations)

Results:
Annual Electric Generation



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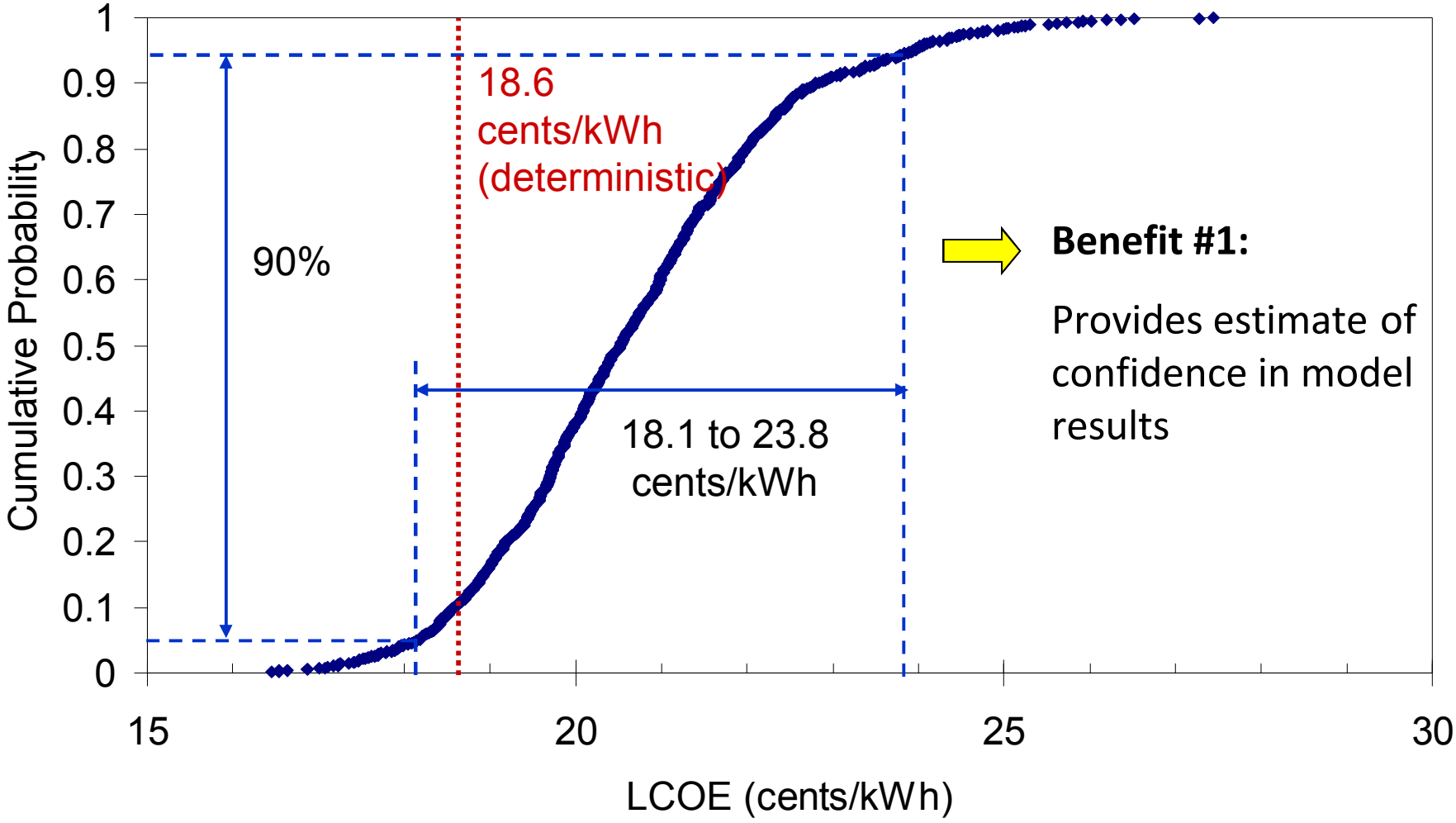
Results:
LCOE (real)



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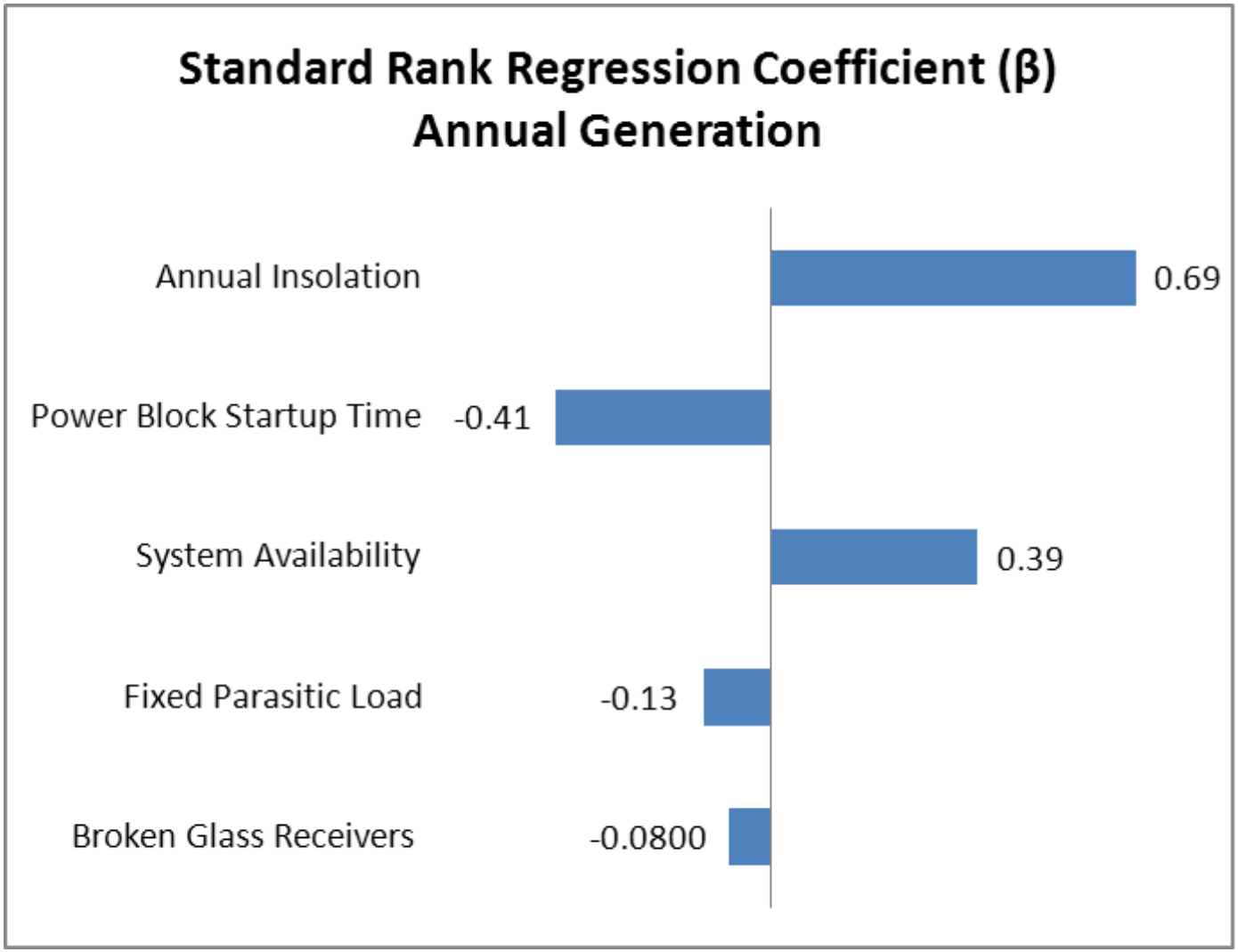
Sensitivity Analysis:
Annual Electric Generation



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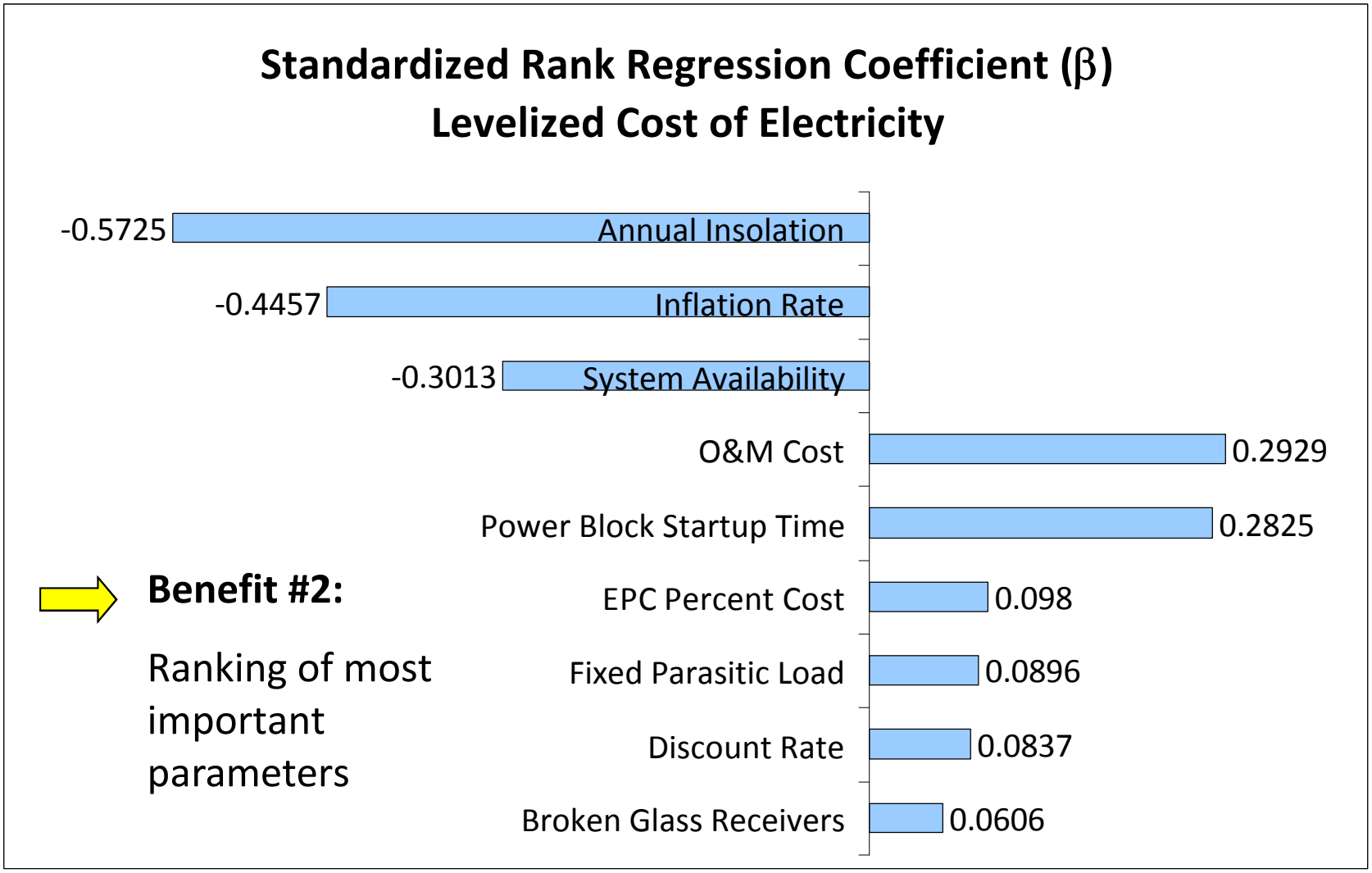
Sensitivity Analysis:
LCOE (real)



Benefit #2:

Ranking of most important parameters

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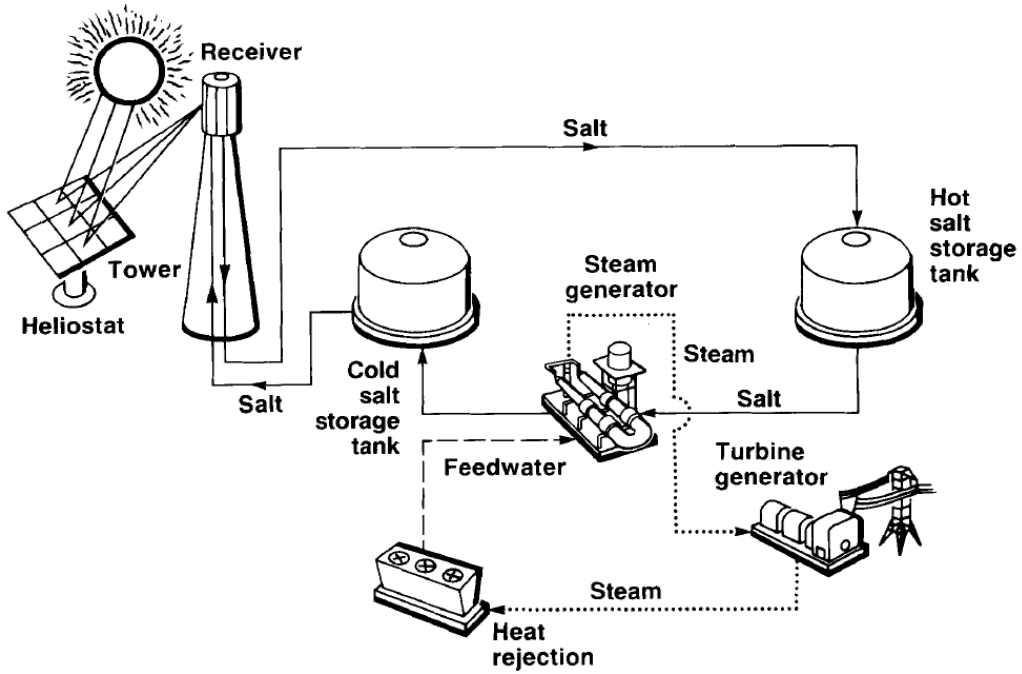
Power Tower Example

(Finch and Ho, 2011)



- 100 MWe molten-salt power tower system
  - 30 year plant life
  - Storage capacity of 9 hours
  - TMY weather data from Daggett, CA
    - Direct normal insolation = 2.8 MWh/m2/yr

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Uncertain Parameters

SAM Input (TIO)		Present Day	Future Goal
Availability	(%)	90	94
Balance of Plant (BOP) Cost	($/kWe)	350	250
Cycle Efficiency	(%)	42.5	48
EPC and and Owner Cost	(%)	25	15
Fixed Costs by Capacity	($/kW-yr)	65	50
Image Error	(mrad)	1.53	1.25
Investment Tax Credit (ITC)	(%)	30	10
Mirror Reflectance and Soiling	(%)	89.3	92.6
Powerblock Cost	($/kWe)	1000	800
Receiver Emissivity	(%)	88	44
Receiver Cost Scaling Exponent	-	0.7	0.53
Solar Collector Field Cost	($/$m^2$)	200	120
Storage Cost	($/kWt)	30	20

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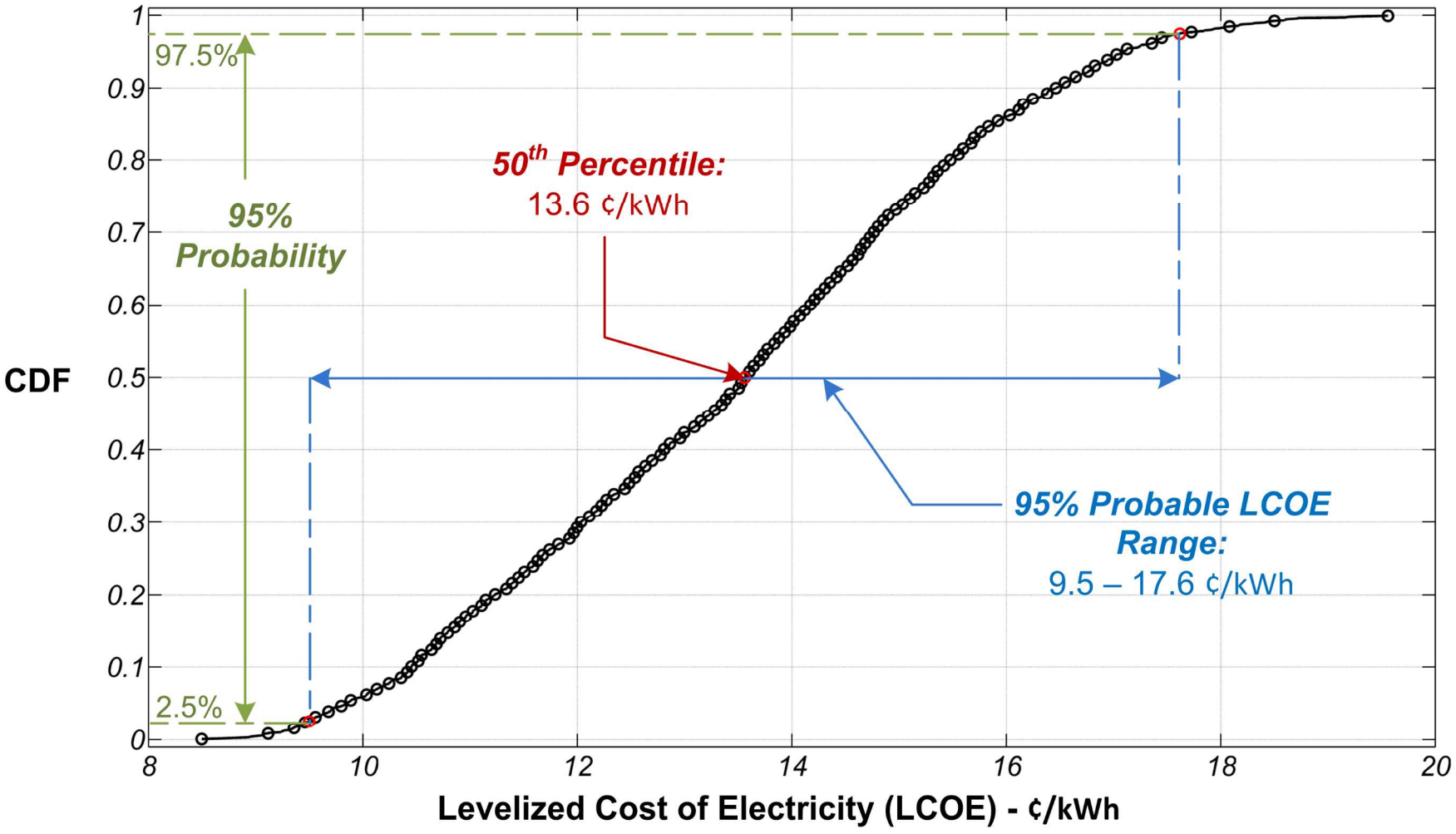
Results: LCOE Uncertainty



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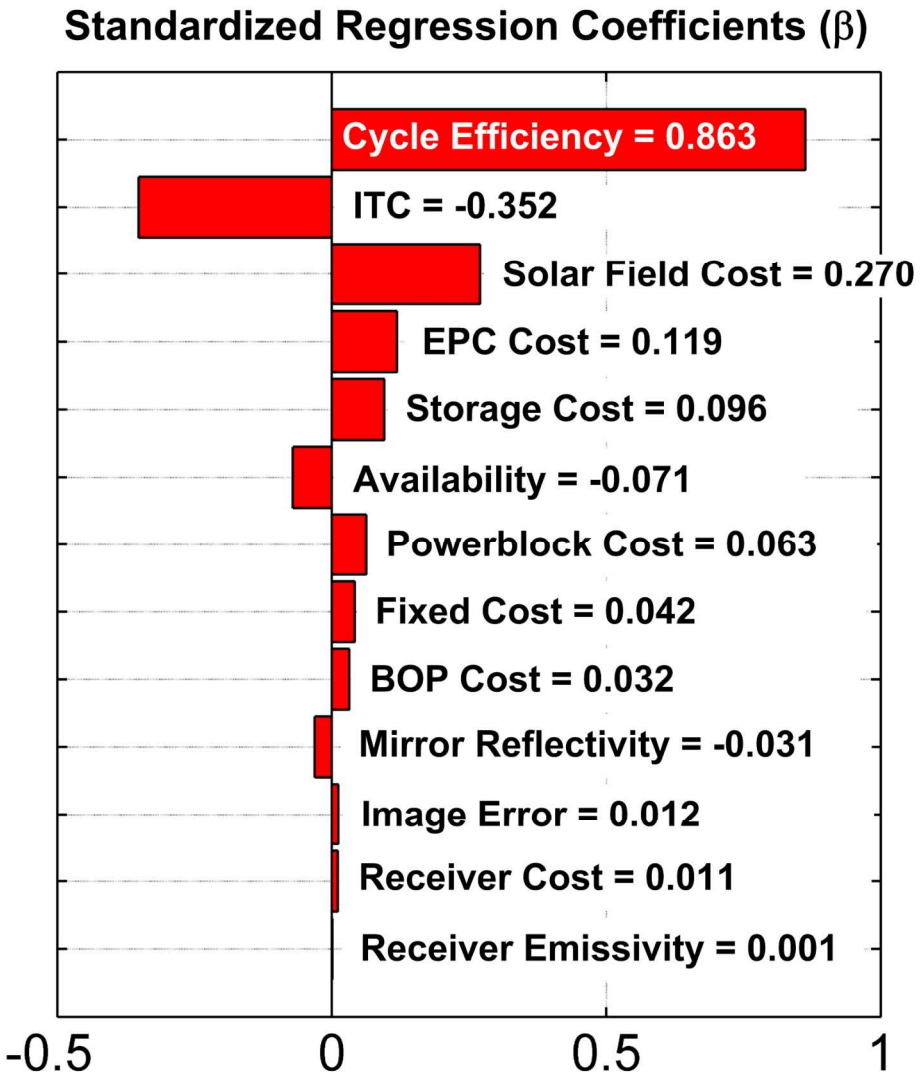
Results: LCOE Sensitivity



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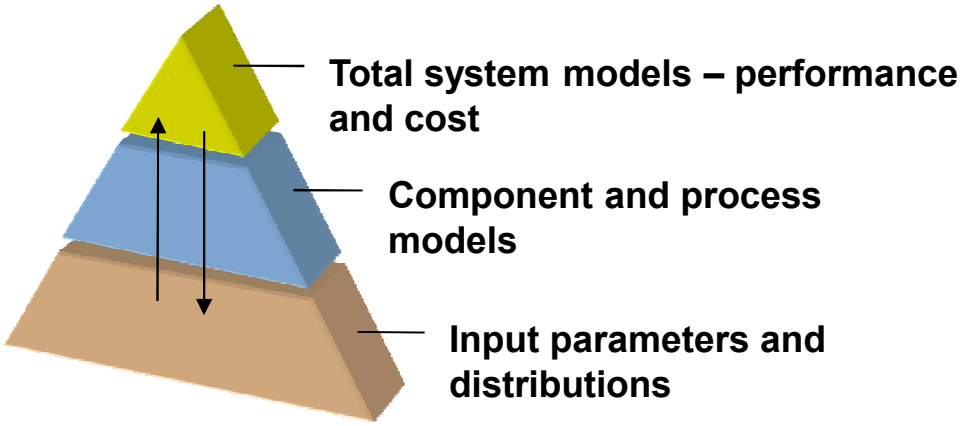
Summary

- **Need to honor and propagate uncertainties through total system**



- **Probabilistic modeling for CSP**
  - Uncertainty analyses will provide companies with more confidence and reliability in their cost/performance models
    - Quantify likelihood of achieving cost and performance metrics
  - Sensitivity analyses will prioritize R&D to focus on system components that have the most impact

- **Probabilistic modeling has been incorporated into SAM**

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Ongoing Work

- **Develop database of uncertainty distributions and CSP modeling protocols**
  - SolarPACES Task 1: Guidelines for CSP Modeling
  - Towers, troughs, dishes, weather
- **Evaluate reliability models and uncertainty distributions**
  - Incorporation into SAM