COMPARISON OF UNCERTAINTIES IN POWER PLANT MODELING AND REAL WORLD DATA
光伏电站产能建模不确定度与实测数据对比

Boris Farnung, Björn Müller

Fraunhofer Institute for Solar Energy Systems ISE

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商用电站质量保证

Quality Assurance for utility scale PV plants

DEVELOPMENT

- solar resource assessment
- site analysis
- environmental stress assessment
- design review and optimization
- feasibility studies

ENGINEERING

- yield assessment
- component bench-marking:
  - module power and energy rating
  - inverter testing

PROCUREMENT

- representative module sampling and checks:
  - performance
  - reliability
  - workmanship

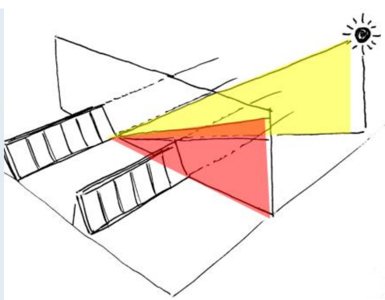
COMMISSIONING

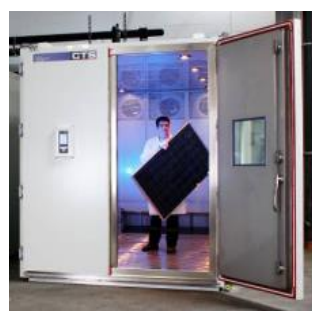
- final power plant test:
  - visual inspection and thermography imaging
  - module power measurements
  - initial performance verification
- final acceptance report

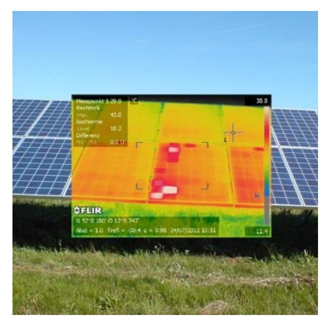
OPERATION

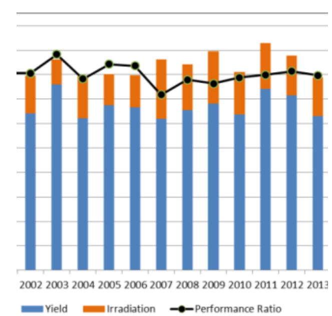
- continuous long-term performance reporting
- failure analysis and reporting
- optimization and re-powering
- warranty check

- technical and financial due dilligence*
- comprehensive PV plant certification*









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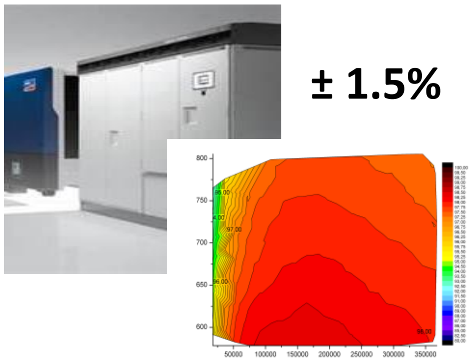
财务评估的基础 - 产能分析
Yield assessment as basis for the financial assessment

- 独立性与精确的模拟　independent, accurate simulation
- 禁得起验证的详细文档　detailed documentation with validated results
- **不确定度报告　Uncertainty statement**

Calculation step	Uncertainty*	Value	Unit	Gain/Loss**	PR***
Irradiation global horizontal	5.0%	1550	kWh/m²		
Irradiation on tilted surface	2.5%	1821	kWh/m²	17.5%	100.0%
Shading					
External Shading	0.5%	1803	kWh/m²	-1.0%	99.0%
Internal Shading	2.0%	1765	kWh/m²	-2.1%	96.9%
Soiling	1.0%	1739	kWh/m²	-1.5%	95.5%
Reflection losses	0.5%	1695	kWh/m²	-2.5%	93.1%
Deviation from STC operation of modules					
Spectral losses	1.0%	1661	kWh/kWp	-2.0%	91.2%
Irradiation-dependent losses	1.0%	1682	kWh/kWp	1.3%	92.4%
Temperature-dependent losses	1.0%	1634	kWh/kWp	-2.9%	89.7%
Interconnection losses (mismatch)	0.5%	1602	kWh/kWp	-2.0%	88.0%
Cabling losses	0.5%	1579	kWh/kWp	-1.4%	86.7%
Inverter losses	1.5%	1538	kWh/kWp	-2.6%	84.5%
Power limitation of inverter	0.5%	1538	kWh/kWp	0.0%	84.5%
Transformer	0.0%	1538	kWh/kWp	0.0%	84.5%
Total	**6.5%**	**1538**	**kWh/kWp**		**84.5%**

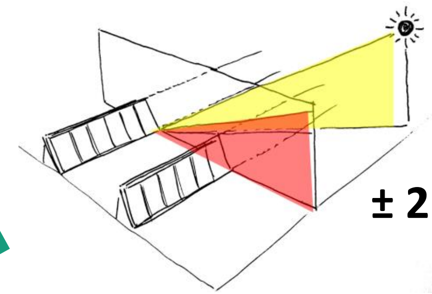
* Uncertainties are related to single standard deviation
** Gain/Los : energetic Gain / Loss according to the step of calculation of the simulation
*** PR: Performance Ratio

产能分析数据与不确定度
Input data for yield prediction and uncertainties

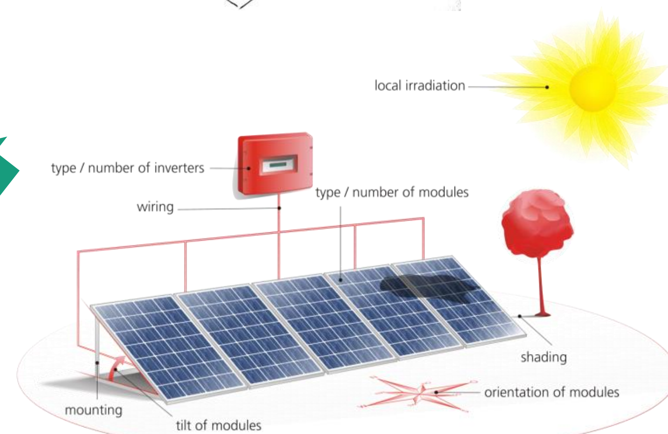


± 1.5%

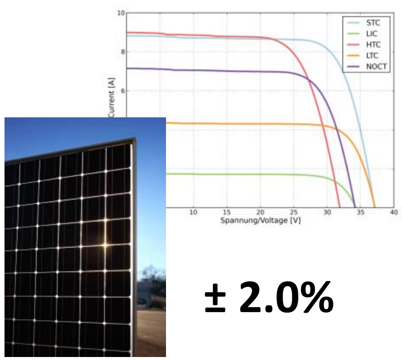
±5%



± 2.0%



± 0.5 to 1.0%



± 2.0%

± 2.0%

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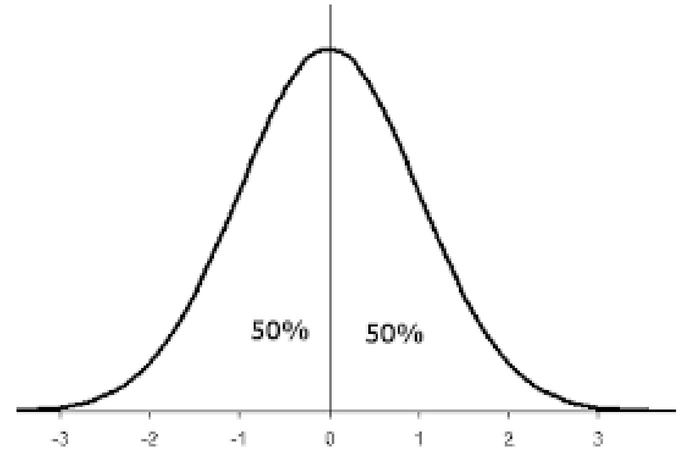
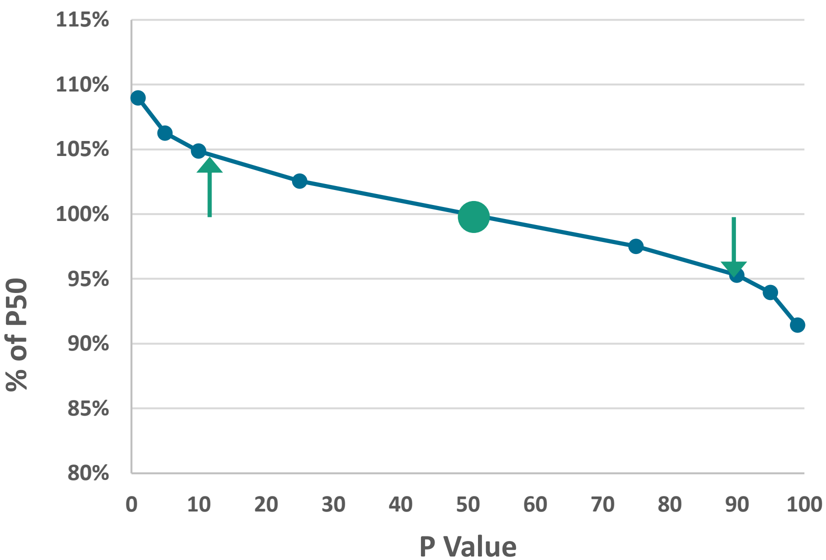
輸入參數為对称的P-函数
Inputs as Symmetric P-Functions

- 输入参数假設為常态„高斯分布”
- P50值和计算结果的平均值相同
- P90到P50的偏差和P10到P50的相同

- Inputs assumed to have normal „Gausian distribution“
- P50 yield same as that calculated for each input parameter at mean value
- Same deviation P90 form P50 as deviation P10 from P50





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财务评估的基础 - 产能分析

Yield assessment as basis for the financial assessment

长期趋势

Long-term trends

造成损耗的因素

Pure losses!

衰减和投入率?

Degradation and Availability ?

计算过程 Calculation step	不确定度 Uncertainty*	数值/单位 Value	Unit	增益/损失 Gain/Loss**	PR链 PR***
Irradiation global horizontal	5.0%	1550	kWh/m²		
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** Gain/Los : energetic Gain / Loss according to the step of calculation of the simulation

两个假设: 每个计算步骤的不确定度均**独立**与**常态分布**

Two simplifications: Uncertainty for individual modeling steps are **independent** and **normal distributed**

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测试数据对比预测的PR和产能
Measured compared to predicted PR and yield

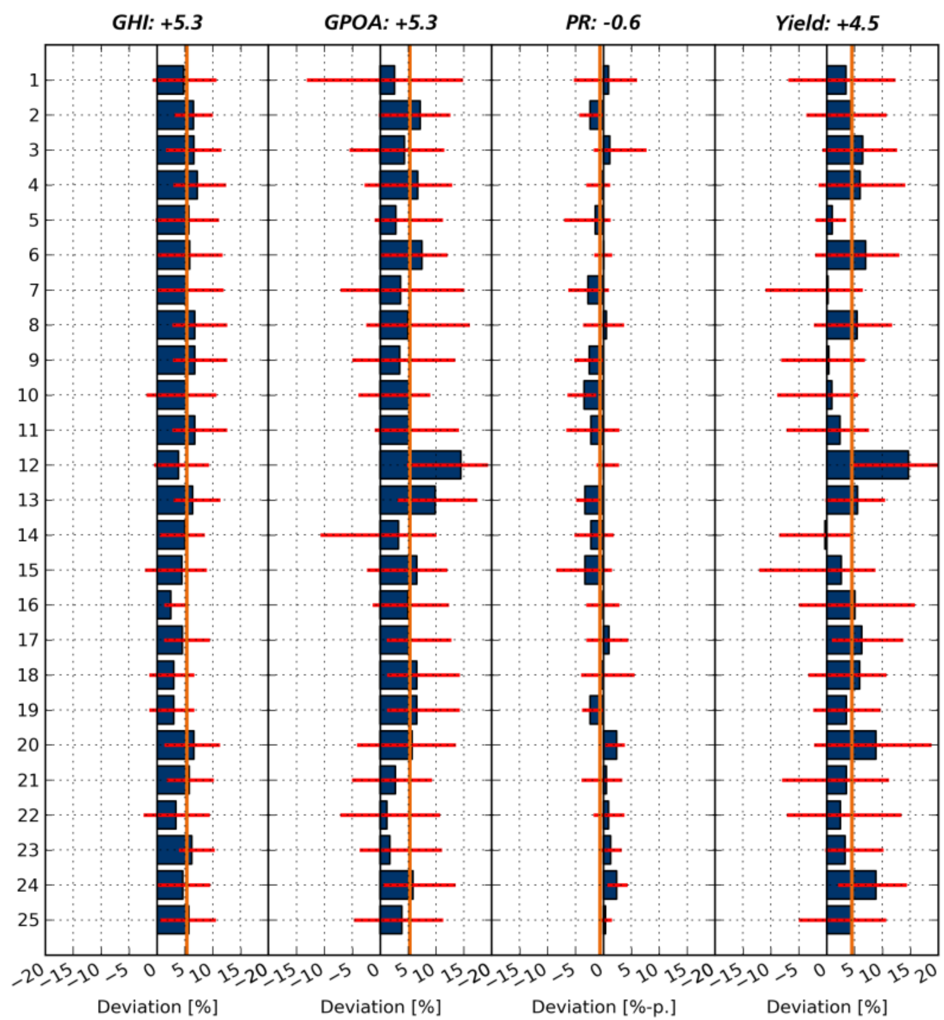
对比结果 Result

- 预测PR和实测值高度吻合
- 辐照值和产能普遍高于预测

- On average very good agreement of measured and predicted PR
- Irradiation and yield remarkably higher than predicted

对比基础 Basis

- 25座电站及其5年高精测量数据
- 25 PV Plants with 5 years highly accurate data



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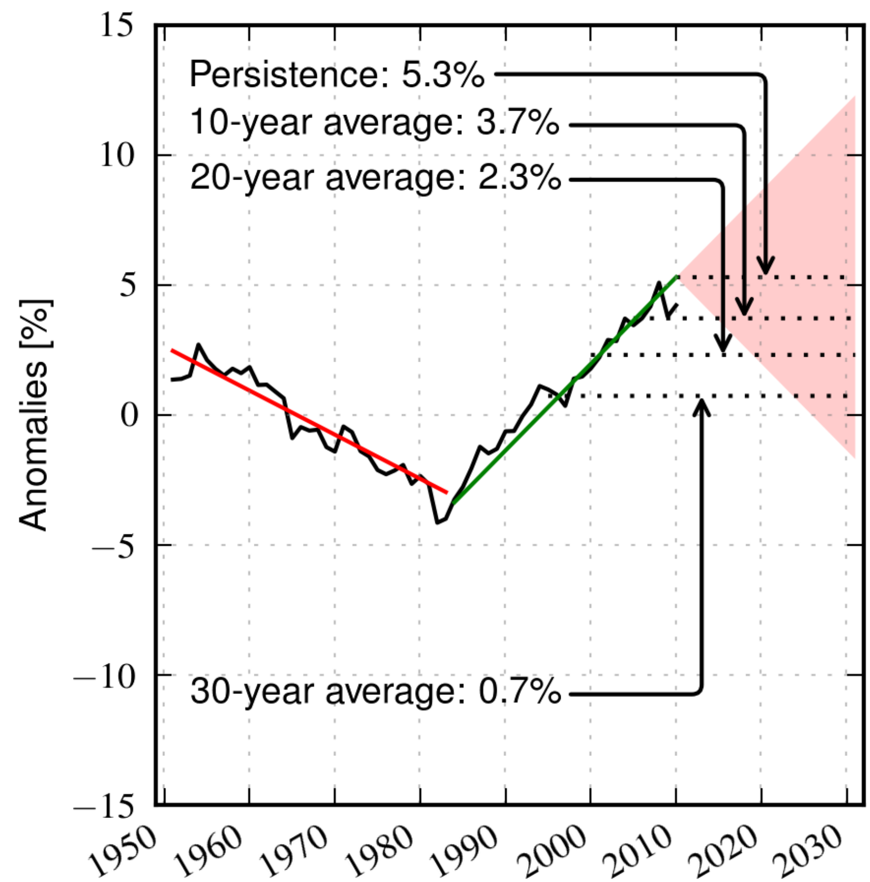
产能分析数据与不确定度
Input data for yield prediction and uncertainties

- (以德国为例)今日的辐照值大于长期平均值约5%
- 使用“旧”的辐照数据可能会低估未来的实际辐照值

- Solar irradiation in Germany today about 5% above long-term average
- Use of “old“ irradiation data underestimates the potential



Müller et. all: Rethinking solar resource assessments in the con-text of global dimming and brightening. Solar Energy 99 (2014)

产能分析数据与不确定度

Input data for yield prediction and uncertainties

- 辐照数据不确定度很高
- 太阳黯化与亮化影响甚巨
- 取用的数据时间轴将大大影响结果

- High uncertainty from irradiation data
- Dimming and brightening has a remarkable impact on the predicted yield
- High influence depending on the time period used

Observed tendencies in surface solar radiation

	1950s-1980s	1980s-2000	after 2000
USA	-6	5	8
Europe	-3	2	3
China/Mongolia	-7	3	-4
Japan	-5	8	0
India	-3	-8	-10

M. Wild et al.: From dimming to brightening: Decadal changes in solar radiation at the Earth's surface. Science 308 (2005)

➡ 辐照数据源和取用时间段必须谨慎选择，以降低预测失真风险

Source and time period of irradiation data holds a high risk and must be assessed and selected carefully for accurate yield assessments

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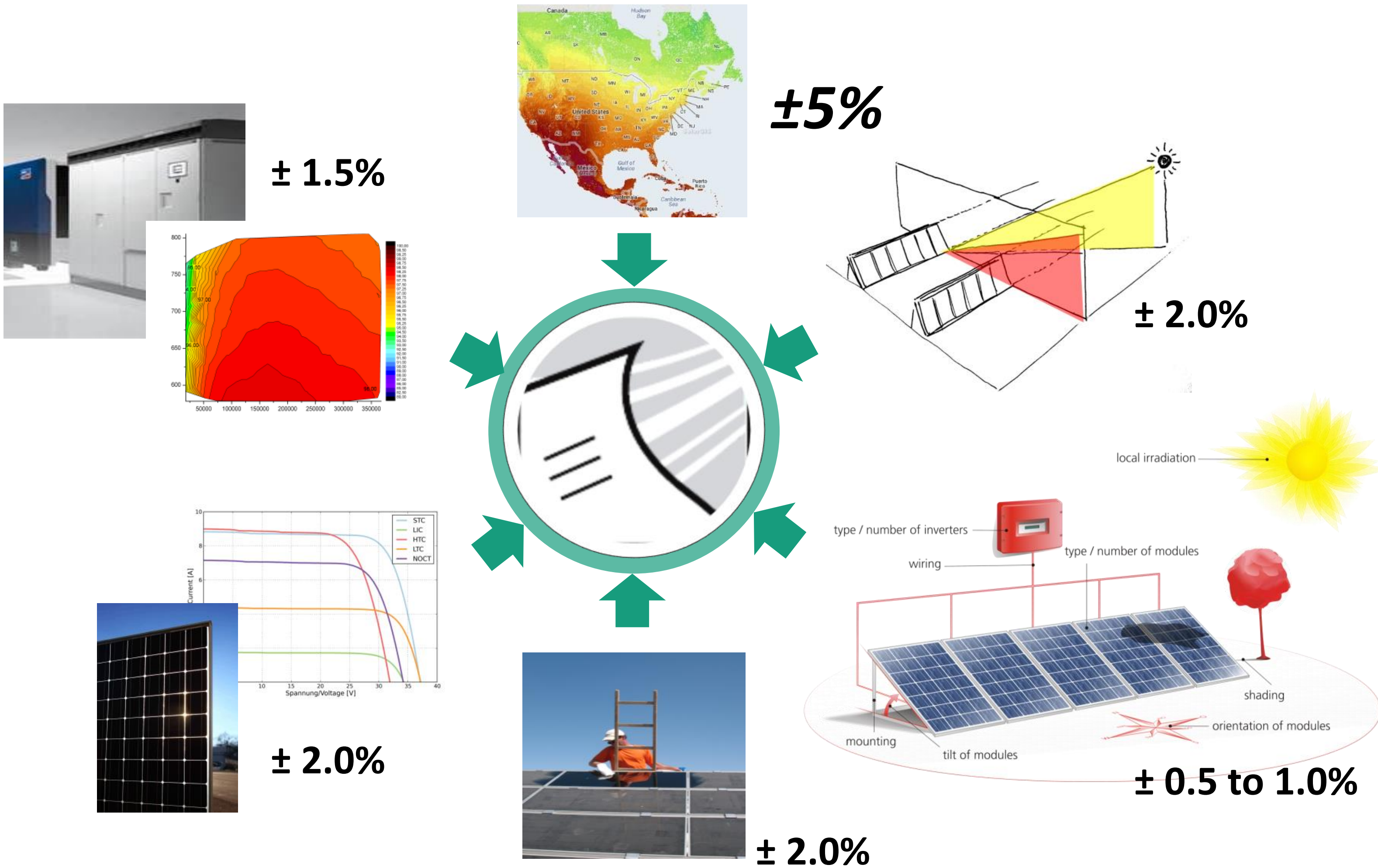
产能分析数据与不确定度

Input data for yield prediction and uncertainties



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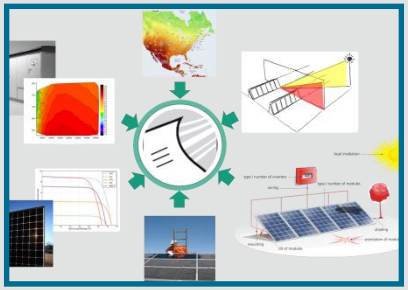
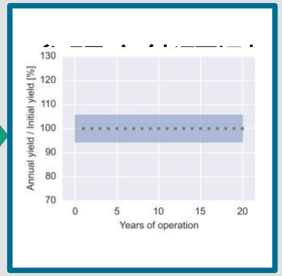
从决定性到概率性的产能预测值
From Deterministic to Probabilistic Yield Values

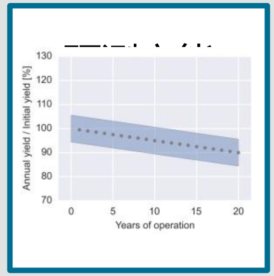
决定性的 Deterministic

长期电站效能(衰减, 有效性…)

Long-term performance
of the PV Power Plant
(degradation, availability…)







气候变化

Climate
change

概率性的 Probabilistic

损失因素, 气候变化, 长期效能的P-函数

P-functions for loss factors, climate
change, long-term performance

蒙地卡
罗法

Monte
Carlo

P-函数产能

P-Function
Yield

年际变化量

Interannual
variability

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不确定度评估 Uncertainty estimation

Calculation step	对称的 Symmetric (假定所有参数均为常态分布) (assuming normal distributions for all parameters)		不对称的 Asymmetric (对每一参数选择常态分布或是三角分布) (individually selecting normal and triangular distributions)			
	Parameter		Distribution	Parameter		
	µ	б	Normal	µ	б	
			Triangular	a	b	c
	%	%		%	%	%
Solar ressource potential in the reference period						
GPOA	11.4	2.5	normal	11.4	2.5	
Yield in the reference period						
Horizon shading	0	0.5	triangular	-1.0	0	0
Row-shading	-1.0	2.0	triangular	-5.0	0	-1.0
Soiling	-0.5	0.5	triangular	-1.5	0	-0.5
Reflection	-3.1	0.5	triangular	-4.1	-2.6	-3.1
STC power	0	2.0	normal	0	2.0	
Spectrum	-1.0	0.5	normal	-1.0	0.5	
Irradiation level	-3.9	1.9	normal	-3.9	1.9	
Temperature	-2.4	1.0	normal	-2.4	1.0	
Mismatch	-0.8	0.5	triangular	-1.8	0	-0.8
DC cabling	-1.5	0.5	triangular	-2.5	-1.0	-1.5
Inverter	-2.7	1.5	triangular	-5.7	0	-2.7
Power limitation	0	0.5	triangular	-1.0	0	0
Transformer	-1.0	0.5	triangular	-2.0	-0.5	-1.0
Yield in the prediction period						
System behavior	-0.6	0.5	triangular	-1.6	0	-0.6
Solar irradiation	0	0.3	normal	0	0.3	
Annual variation	0	4.9	normal	0	4.9	

Uncertainties of individual modelling steps used in the exemplary yield simulation. A normal (Gaussian) distribution is characterized by mean value µ and standard deviation б, while a triangular distribution is characterized by minimum a, maximum b, and modus c.

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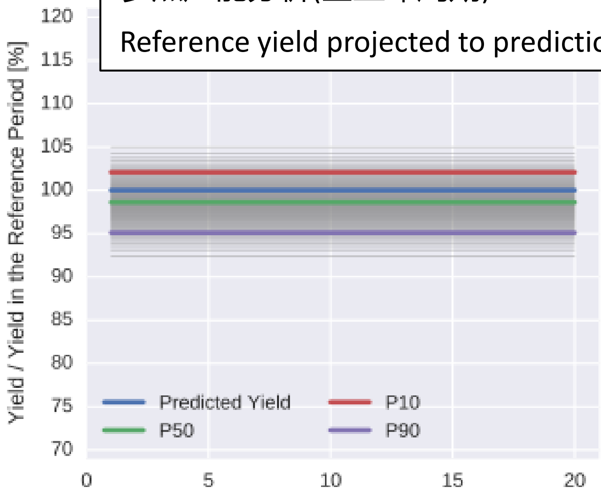
使用蒙地卡罗模拟估算不确定度

Monte Carlo Simulation for Uncertainty estimation

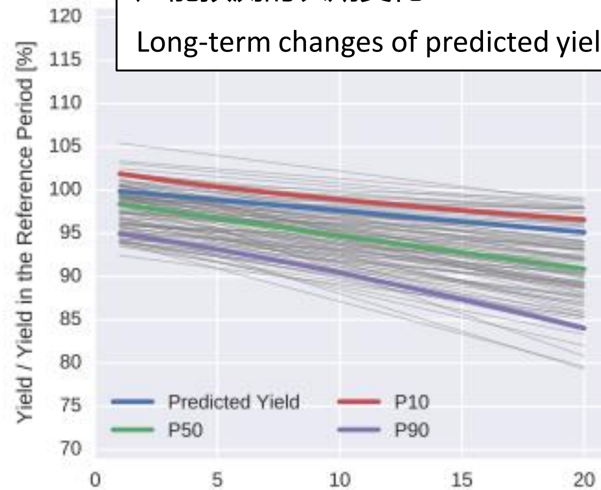
参照产能分析(全生命周期)

Reference yield projected to prediction period



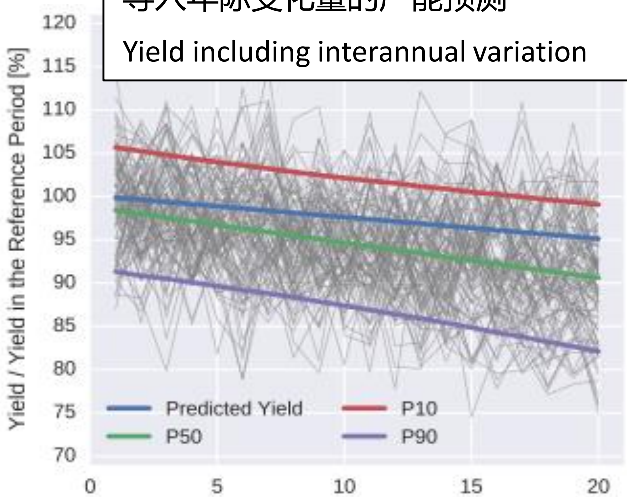
产能预测的长期变化

Long-term changes of predicted yield



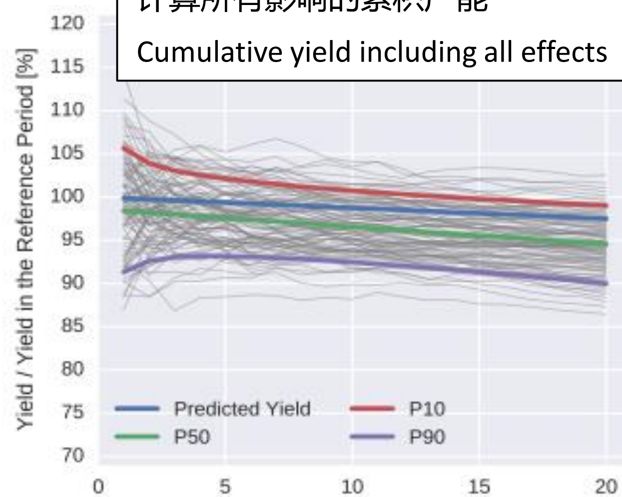
导入年际变化量的产能预测

Yield including interannual variation



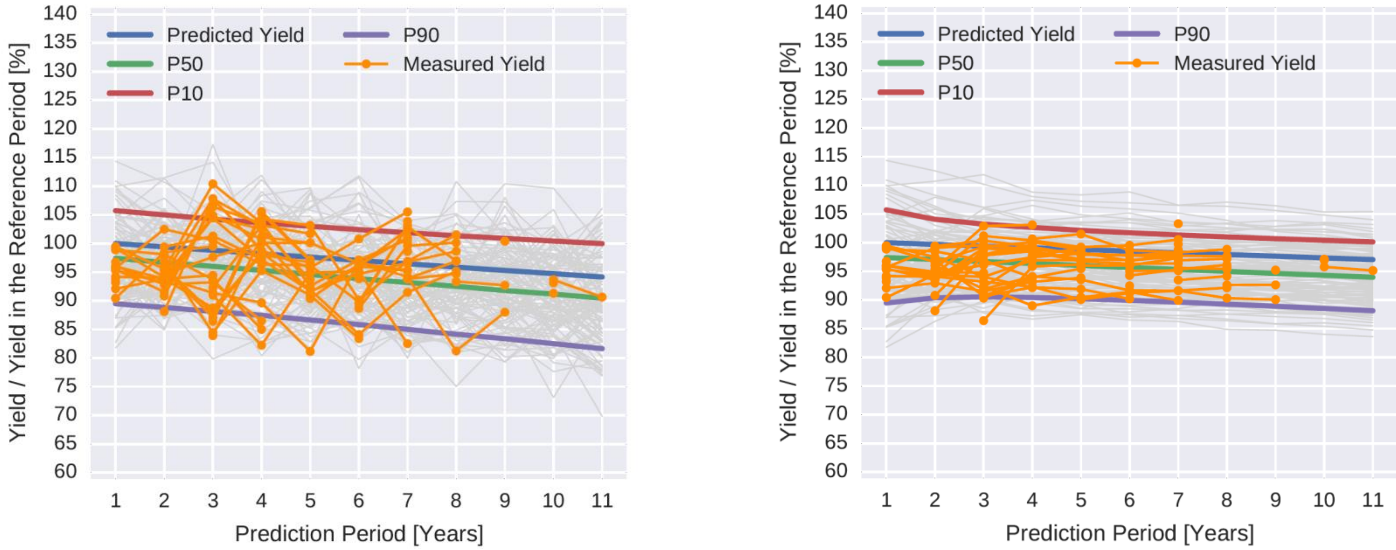
计算所有影响的累积产能

Cumulative yield including all effects



B. Müller et al.: Framework to Calculate Uncertainties for Lifetime Energy Yield Predictions of PV Systems, IEEE 2017

不确定度评估与实测数据比较
Uncertainty estimation compared to real world data



- 实际量测的数据和根据蒙地卡罗模拟的预测结果相近

  measured values fit quite well into the uncertainty range as expected from the Monte-Carlo simulations

B. Müller et al.: Framework to Calculate Uncertainties for Lifetime Energy Yield Predictions of PV Systems, IEEE 2017

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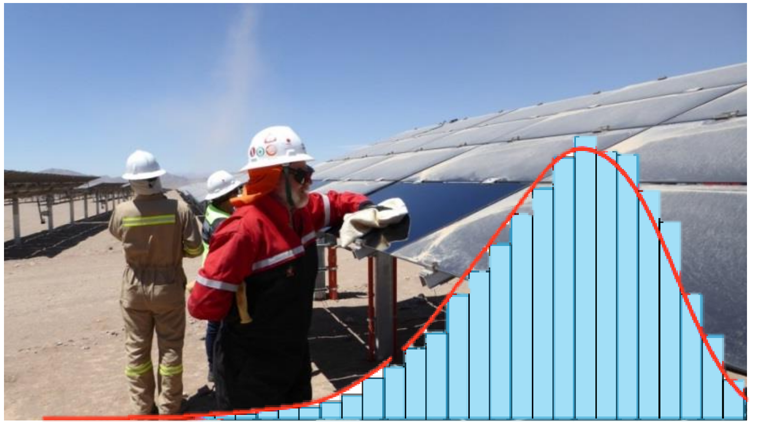
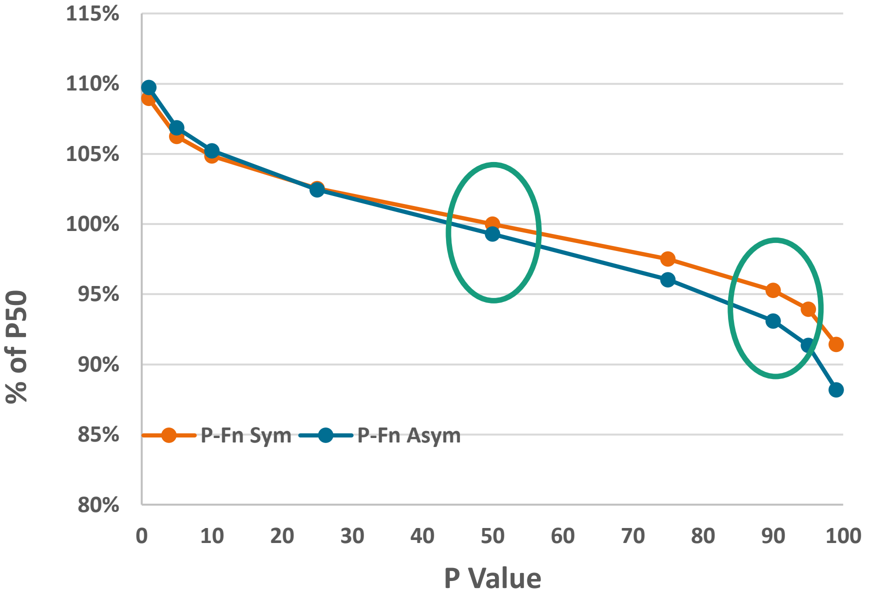
非对称P-函数
Asymmetric P-Functions

- 不对称函数的P50值低于对称函数的P50值
  →實際產能更低的可能性較大
- P90值均低于其在对称函数中的值。可能低至~5%
- 投资者必需知道!! 高預測產能≠好的預測
  投資回報風險!
- P50 with asymmetric P-Fn now less than P50 with symmetric P- Fn.
  →Bad outcomes more likely
- P90 worse than with symmetric e.g. could be hit by ~5%.
- Investor needs to know!!
  Higher result ≠ better predication
  Risk of return!





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感谢您的参与!
Thank you for your Attention!

Fraunhofer Institute for Solar Energy Systems ISE

Boris Farnung, Björn Müller

boris.farnung@ise.fraunhofer.de

Main author Björn Müller, co-authors Wolfgang Heydenreich, Christian Reise, Boris Farnung

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