LIFE-TIME ENERGY YIELD PREDICTIONS FOR UTILITY-SCALE PV POWER PLANTS

Dr.-Ing. Björn Müller

Fraunhofer Institute for Solar Energy Systems ISE

www.ise.fraunhofer.de

Knowledge Exchange Seminar Photovoltaic Solar Generation, Florianopolis – Brazil

9th of November 2018

© Fraunhofer ISE

Fraunhofer ISE

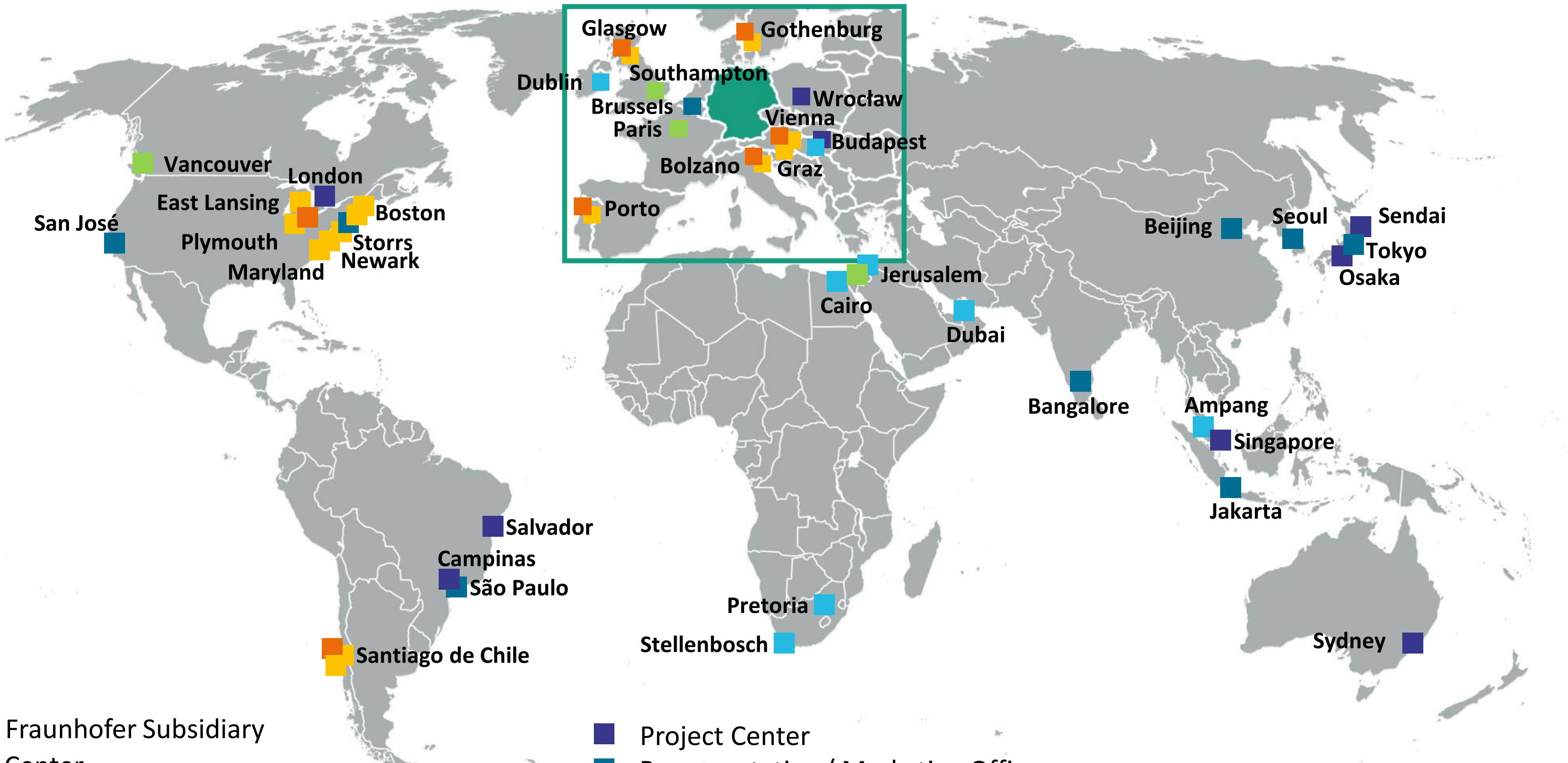
AGENDA

- Introduction
- Yield predictions for PV power plants
- Uncertainties of predicted yields
- Summary and conclusion

© Fraunhofer ISE

The Fraunhofer Gesellschaft

Connected Worldwide



- Fraunhofer Subsidiary
- Center
- ICON / Strategic Cooperation
- Project Center
- Representative / Marketing Office
- Senior Advisor

© Fraunhofer ISE

Fraunhofer ISE

Fraunhofer Institute for Solar Energy Systems ISE

12 Business Areas

Photos © Fraunhofer ISE

- Silicon Photovoltaics
- III-V and Concentrator Photovoltaics
- Dye, Organic and Novel Solar Cells
- Photovoltaic Modules and Power Plants
- Storage Technologies
- Hydrogen and Fuel Cell Technology
- Solar Thermal Technology
- Energy Efficient Buildings
- Energy Efficient Power Electronics
- Zero-Emission Mobility
- System Integration and Grids – Electricity, Heat, Gas
- Energy System Analysis

© Fraunhofer ISE

Fraunhofer ISE

Photovoltaic Modules and Power Plants

Quality Assurance for utility scale PV

Planning and Design

- Solar resource and yield assessment
- Manufacturer quality benchmarking
- Module power and Energy rating

Implementation

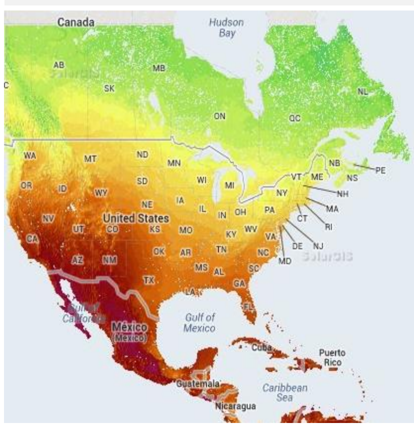
- Module performance check
- Module reliability check
- Module material check

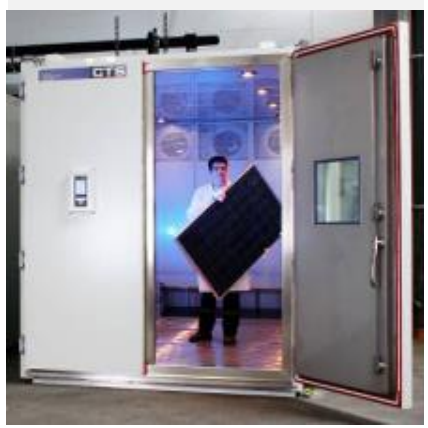
Commissioning

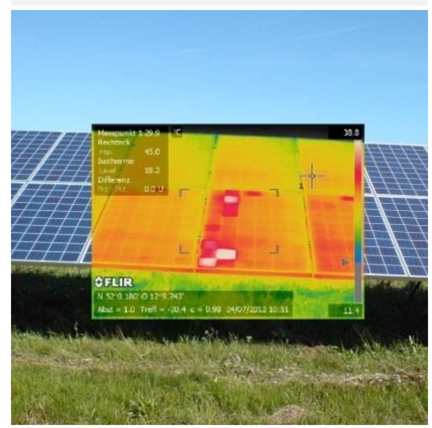
- Final acceptance test
- Initial performance and safety verification
- PV plant certification

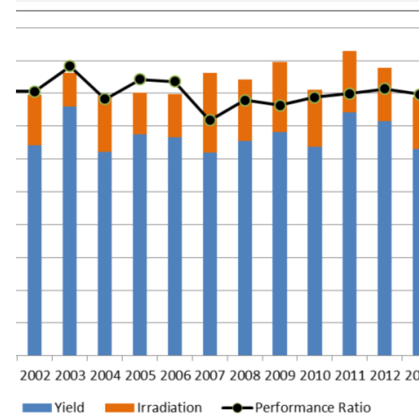
Operation

- Continuous long-term performance reporting
- Failure analyzes and reporting
- Forecasting









© Fraunhofer ISE

Fraunhofer ISE

Fraunhofer ISE and Fotovoltaica / UFSC

Alexander von Humbold Foundation: Research Group Linkage Programme

This scientific visit of Björn Müller to Fotovoltaica/UFSC is being sponsored by an Alexander von Humboldt Foundation Research Group Linkage Programme Research Grant

- http://www.humbold-foundation.de

© Fraunhofer ISE
Fraunhofer ISE

Yield Predictions for PV Power Plants
Yield assessment as basis for the financial assessment

- independent, accurate simulation
- detailed documentation with validated results

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

© Fraunhofer ISE
Fraunhofer ISE

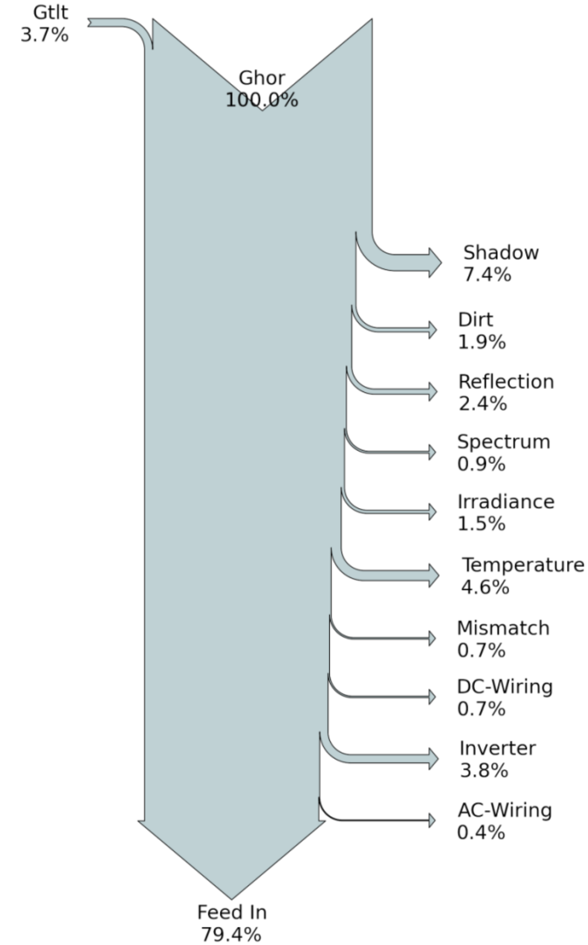
Yield Predictions for PV Power Plants
Procedure

- Assessment of the solar resource and other meteorological quantities
  - Derive meteorological data from the past (reference period)
  - Calculate irradiance in plane of array using a conversion model
- Simulation of the energy output for the PV system under consideration
  - Based on meteorological data and specifications of the PV system
  - Set of models, methods and parameters
- Long-term (future) changes in energy yield within the prediction period
  - Power and performance changes of the PV system
  - Changes of meteorological quantities

© Fraunhofer ISE
Fraunhofer ISE

Yield Predictions for PV Power Plants
Calculation Steps

- Horizontal irradiation (history)
- Horizontal irradiation (future)
- Diffuse fraction & conversion into module plane
- Partial shading (& inverter behavior)
- Soiling losses
- Reflection losses
- Spectral effects
- Product specifications vs. actual properties
- Dependency on irradiance level
- Dependency on temperature
- Mismatch losses
- DC + AC cable losses
- Inverter efficiency and limitations
- Transformer losses
- System degradation



© Fraunhofer ISE
Fraunhofer ISE

Uncertainties of Predicted Yields

Monte Carlo Simulation

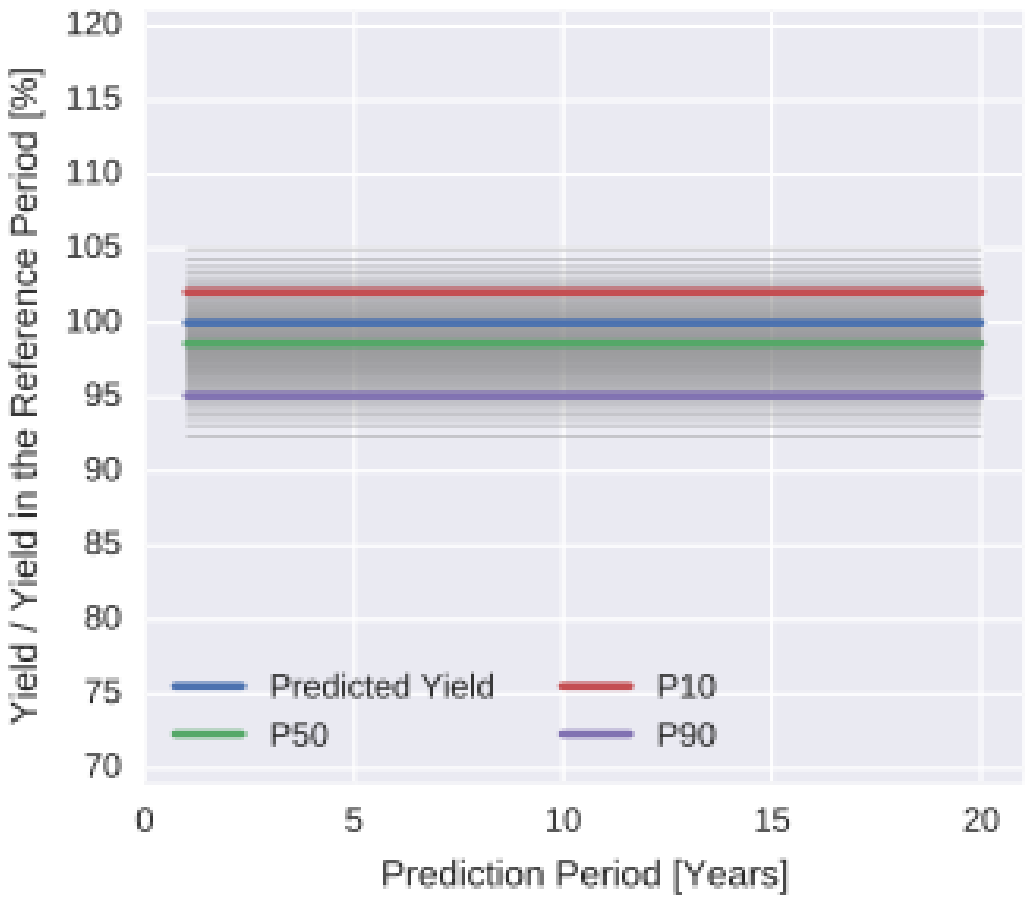
- Why Monte Carlo?
  - To consider the possibly asymmetric uncertainties of all simulation steps
  - Because it's (quite) easy to implement

- Advantages
  - Easy to use non-normal uncertainty distributions
  - Consideration of uncertainties in individual years due to inter-annual variation
  - Results can be directly used for further calculations e.g. financial models

© Fraunhofer ISE

Uncertainties of Predicted Yields
Monte Carlo Simulation

Prediction without long-term changes

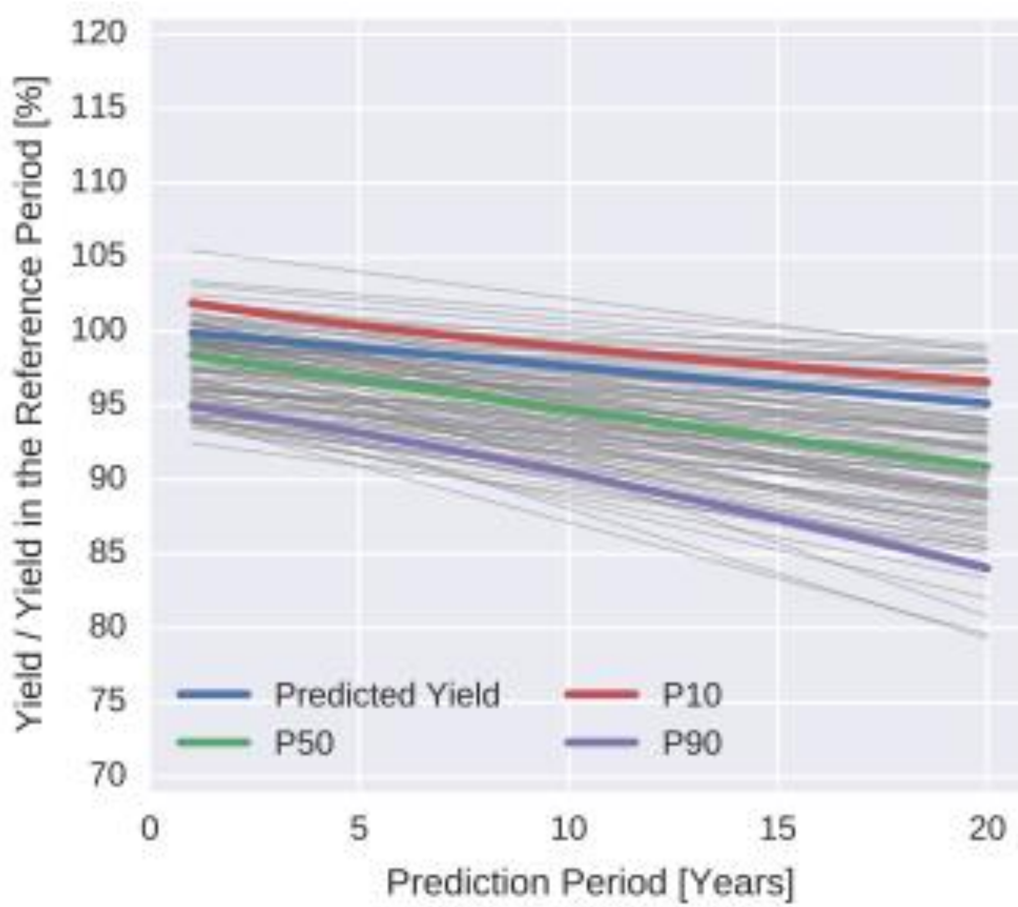


© Fraunhofer ISE
Fraunhofer ISE

Uncertainties of Predicted Yields

Monte Carlo Simulation

Prediction with long-term changes

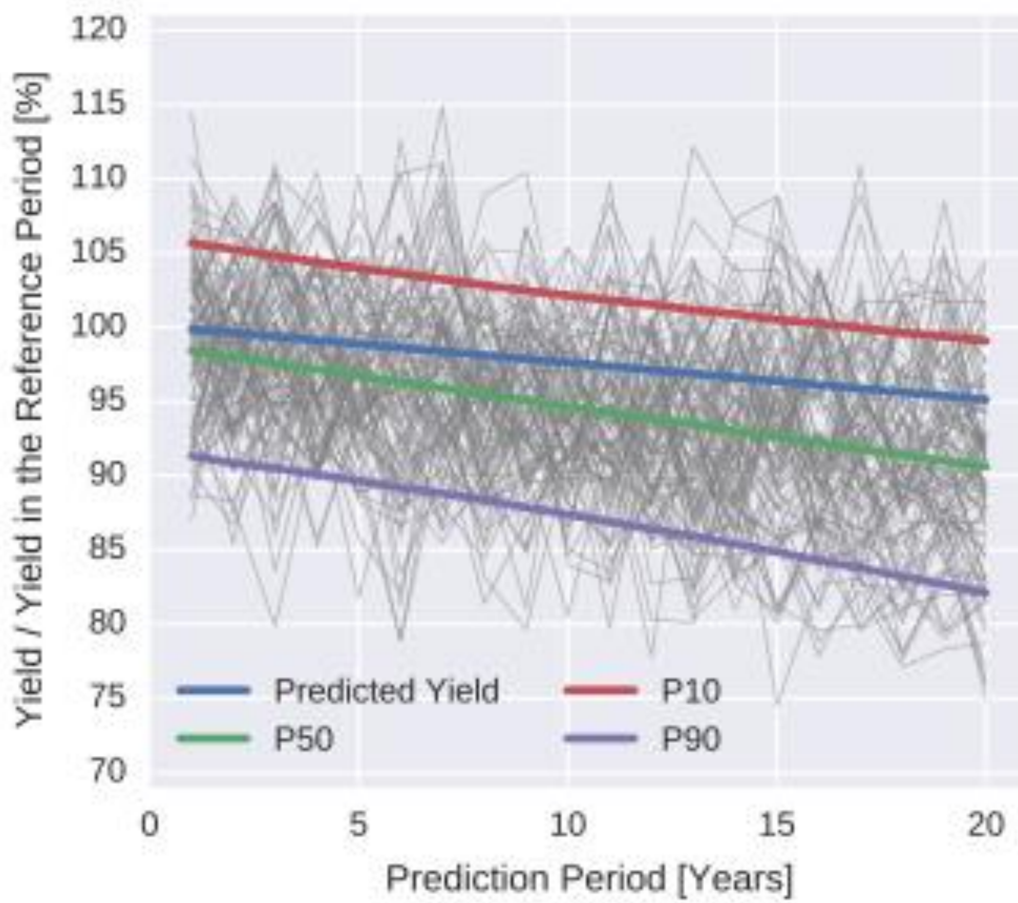


© Fraunhofer ISE

Fraunhofer ISE

Uncertainties of Predicted Yields
Monte Carlo Simulation

Prediction with interannual variations

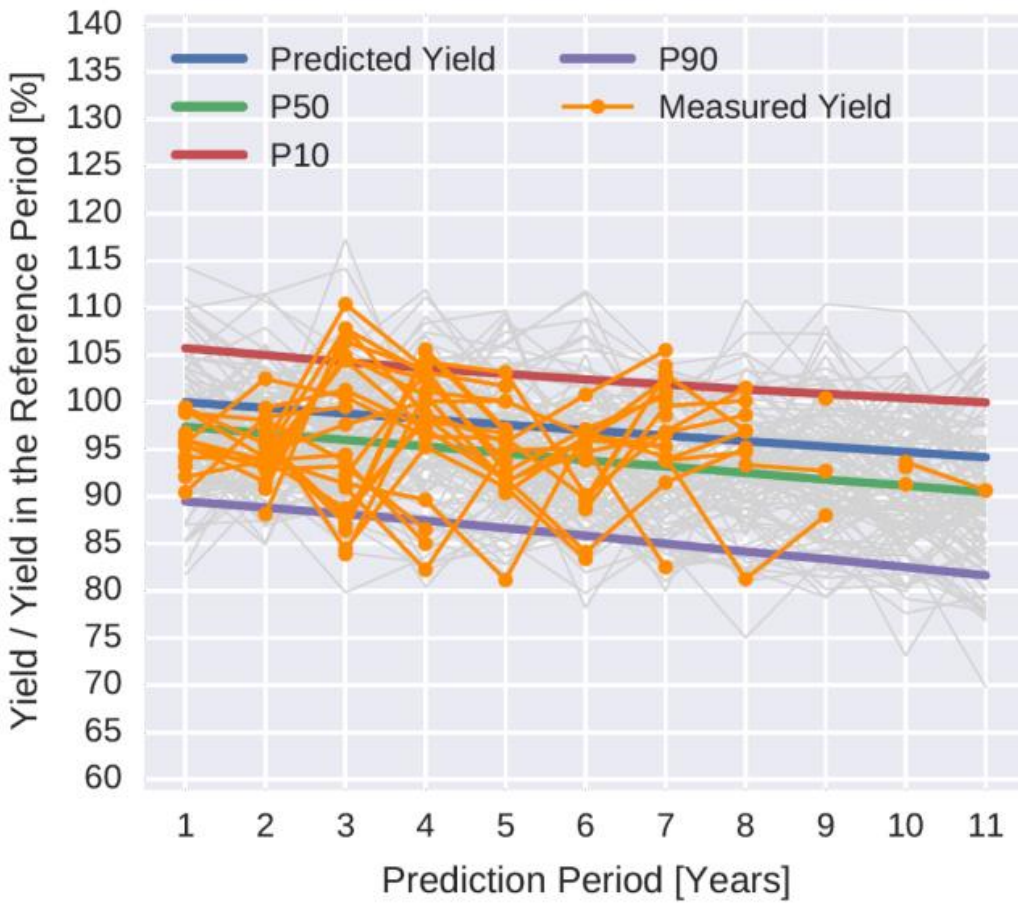


© Fraunhofer ISE
Fraunhofer ISE

Uncertainties of Predicted Yields

Monte Carlo Simulation

Comparison with measured yields



© Fraunhofer ISE

Uncertainties of Predicted Yields

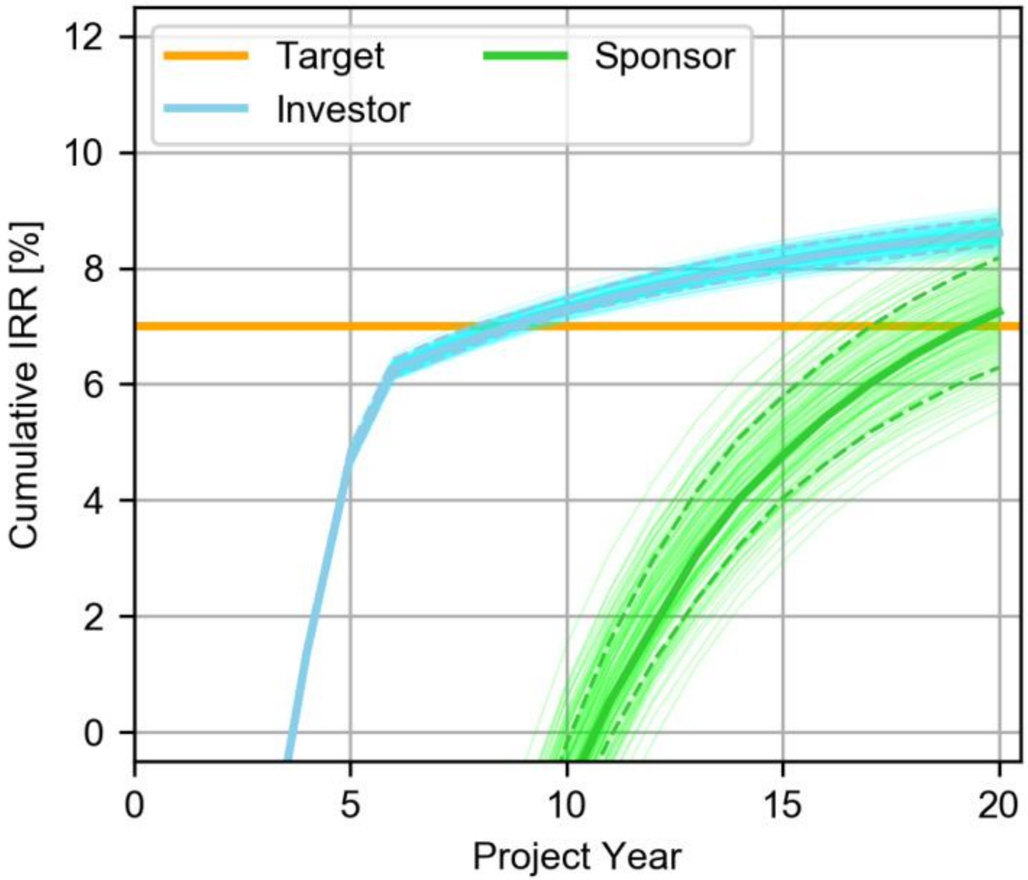
Example: Annual yields as input for financial model

Uncetraintíes of after tax internal rates of return for an “All Equity Partnership Flip” model in the US

Source:

B. Müller, B. Xu-Sigurdson, P.Bostock, B. Farnung

“The Influence of Interannual Variation and Long-term Effects of PV Energy Yields on Financial Models”, 7th WCPEC, Hawaii, 2018



© Fraunhofer ISE

Fraunhofer ISE

Summary and Conclusion

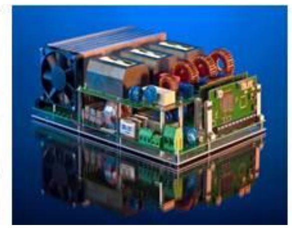
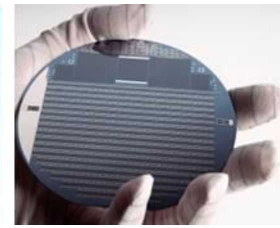
- Independent high quality life-time energy yield predictions
  - are a sound basis for investments in PV power plants
  - can achieve quite low uncertainties

- Monte Carlo based uncertainty estimation
  - is able to reflect “real” (measured) deviations between prediction and measurement
  - can consider asymmetric uncertainty distributions e.g. for degradation rates
  - can be directly used as input for financial models

© Fraunhofer ISE
Fraunhofer ISE

Thank you for your attention!




Fraunhofer Institute for Solar Energy Systems ISE

Björn Müller

www.ise.fraunhofer.de

bjoern.mueller@ise.fraunhofer.de

© Fraunhofer ISE

Fraunhofer
ISE