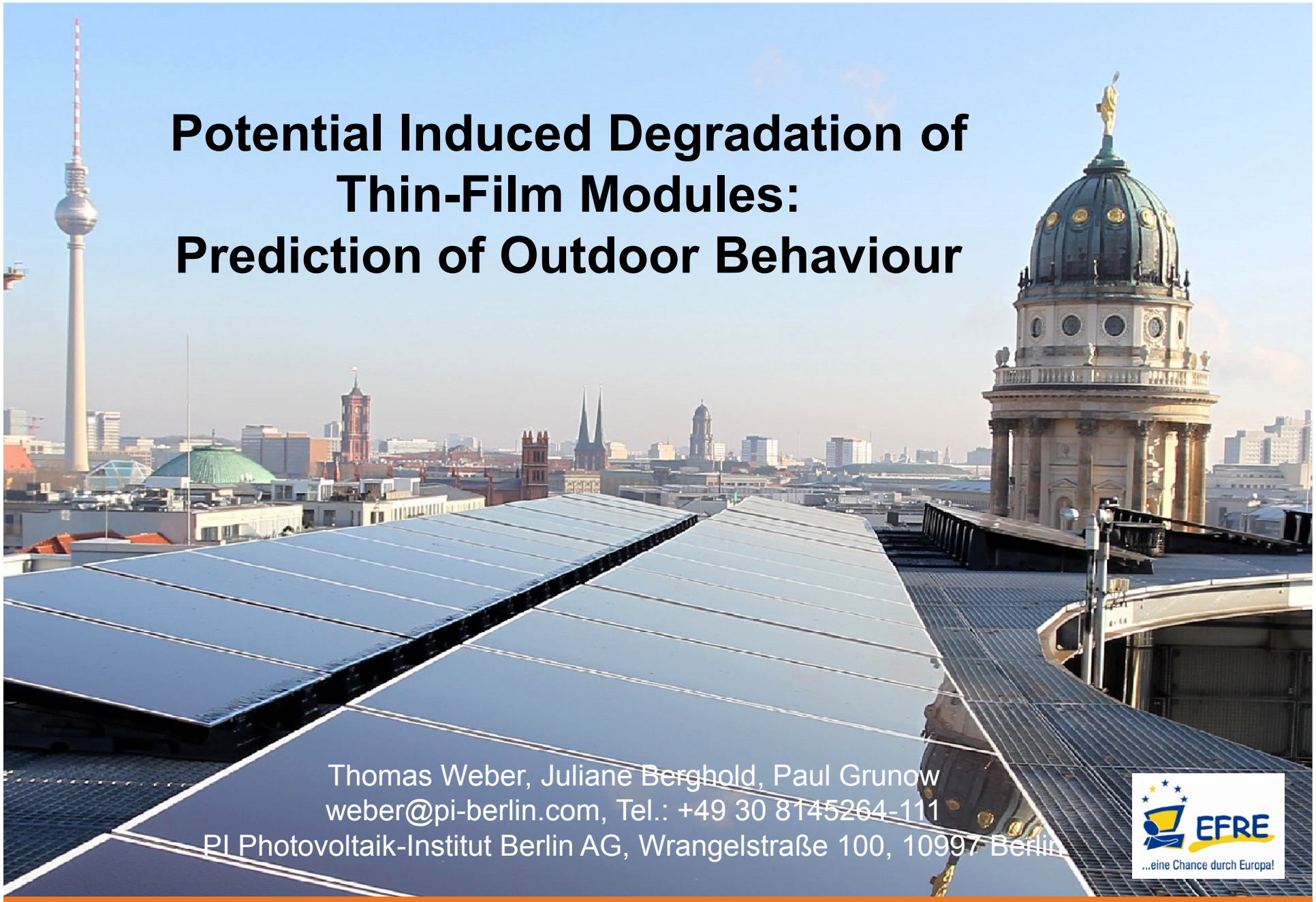
Potential Induced Degradation of Thin-Film Modules: Prediction of Outdoor Behaviour



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Overview

1) About PI Berlin
2) **Motivation**
3) **Introduction** to Potential Induced Degradation (PID)
4) **Results**: How do Modules degrade in the field?
5) Results: **Life-Time Prediction**
6) Summary

1) About PI-Berlin

Customer

PV-Module Quality & Lab Services

- Head of BU: Dipl.-Ing.(FH) Michael Schoppa
- Services: Supplier Qualification, Factory Inspections, Module Tests, Certification

PV-Systems

- Head of BU: P. Eng. Steven Xuereb
- Services: Yield Assessments, Preliminary Design Due Diligence, Plant Inspections

PV-Module Technology and R&D Services

- Head of BU: Dr. Juliane Berghold
- Services: R&D Services, Components Analysis, Expert Opinions, Field Failure Tracking, Consulting, Funded Projects

Report

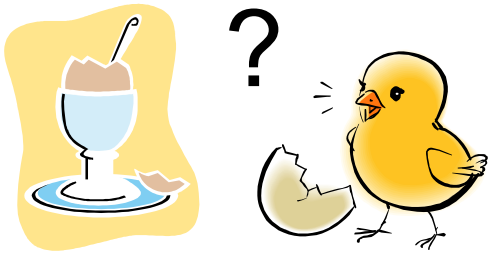
2) Motivation: Why do we want to evaluate PID results?

Module Degradation

- around 15 GW TF Installed in the EU
- test results and field-returns show PID susceptibility

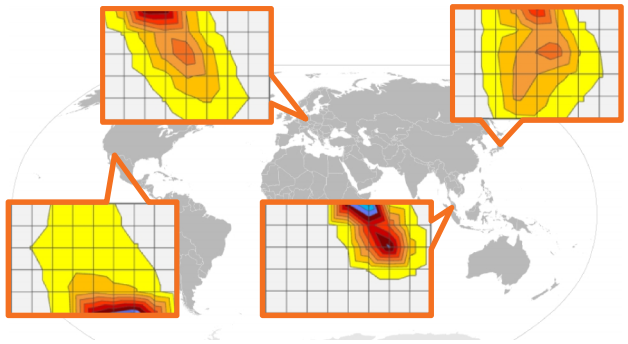
Correlation
In- and Outdoor

- Module tested!
  What happens in the real world?



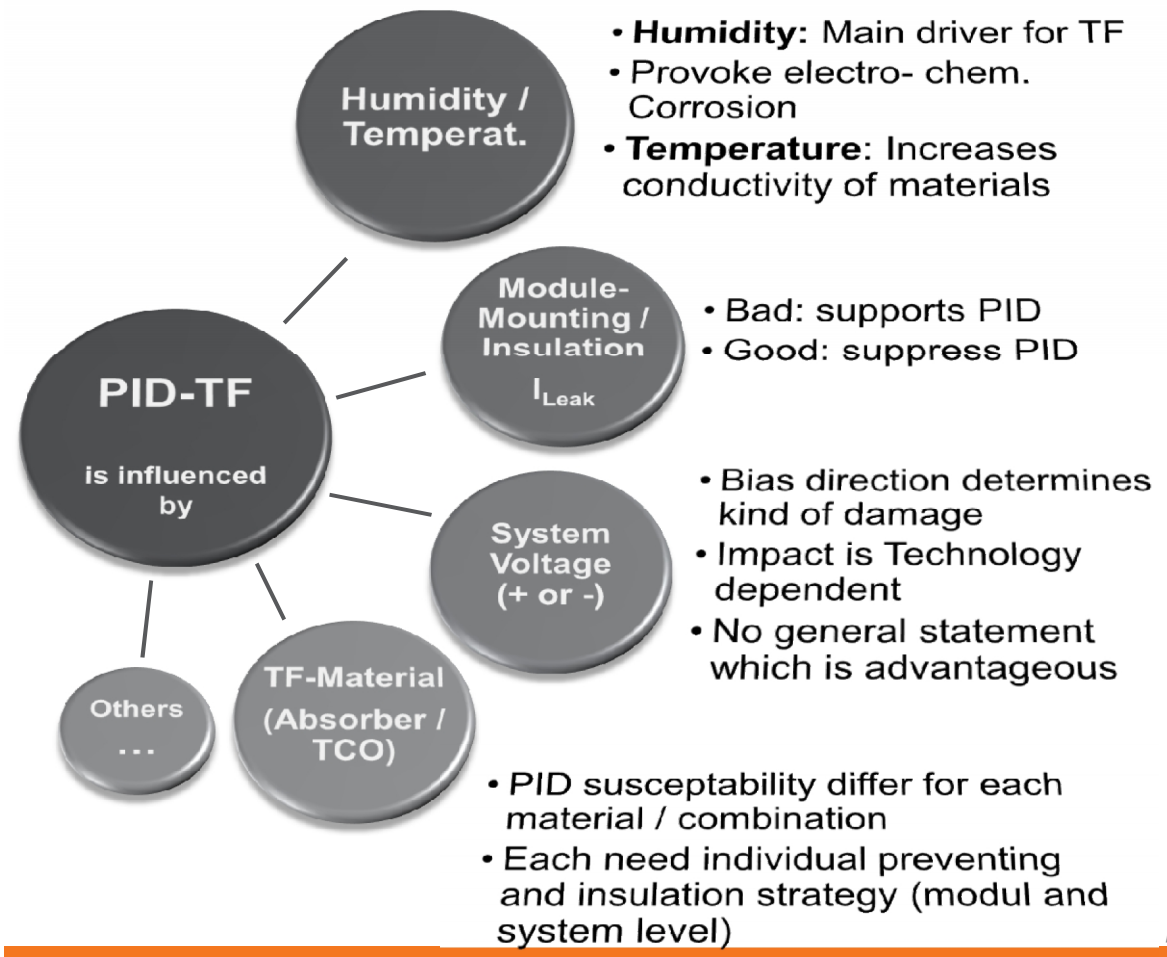
Influence of Location

- Each location has its specific impact on a module.

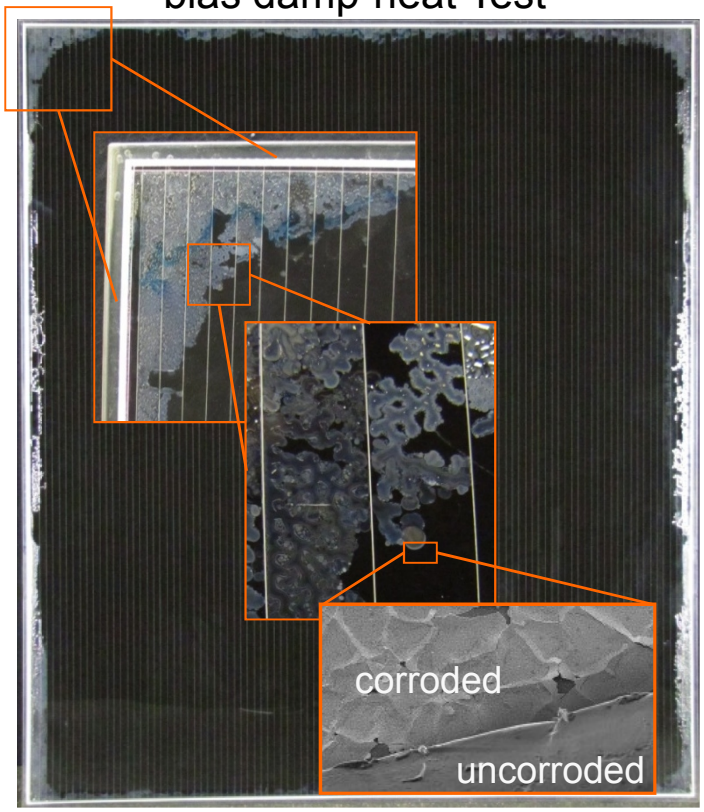


3) Introduction to PID

PID … Potential induced degradation (c-Si & TF, power related degradations)
and TCO-Corrosion … (electro-chem.) Corrosion of the TCO-layer (only µc-Si, CdTe)

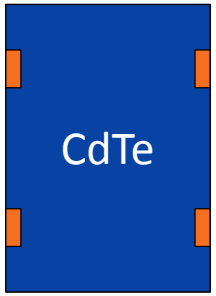


µc-Si Module after 1000h in bias damp-heat Test

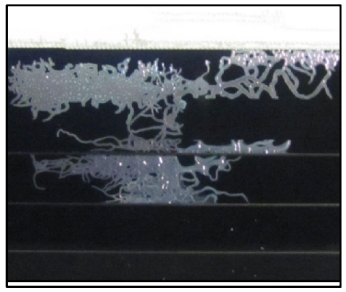


[Weber et .al., 3AV.2.9, EU PVSEC Valencia, 2010]

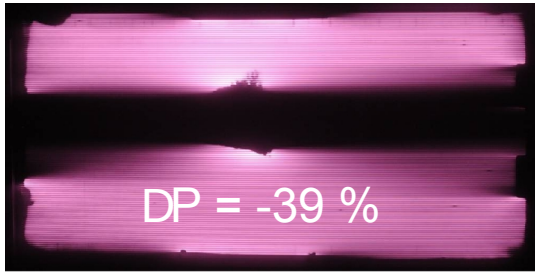
4) How Modules degrade in the field



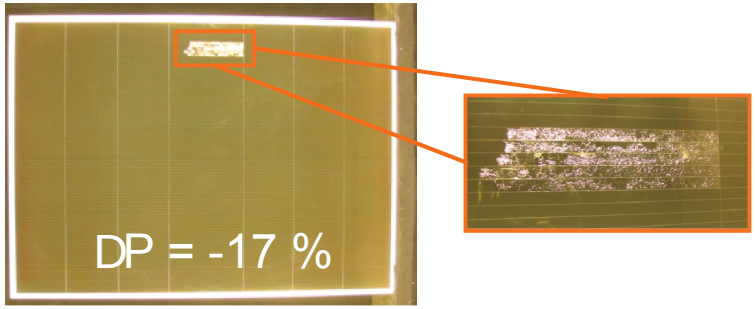
- TCO-Corrosion at the edges
- Power degradation? Not seen yet or not relevant
- EL: reduced signal



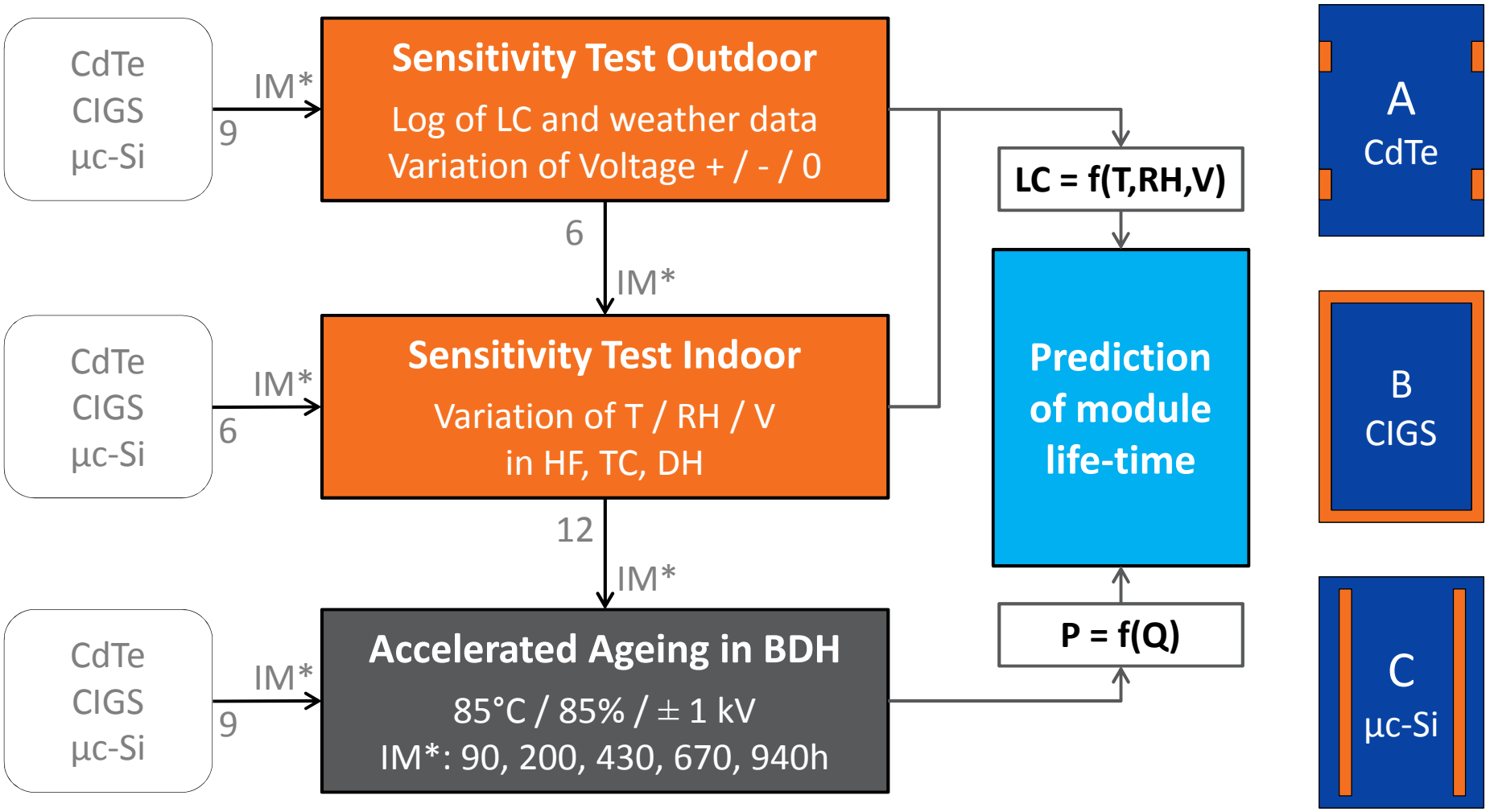
- No TCO-Corrosion visible but
- Power degradation
- EL: reduced signal



- TCO-Corrosion at the edges and apart
- Power degradation
- EL: reduced signal

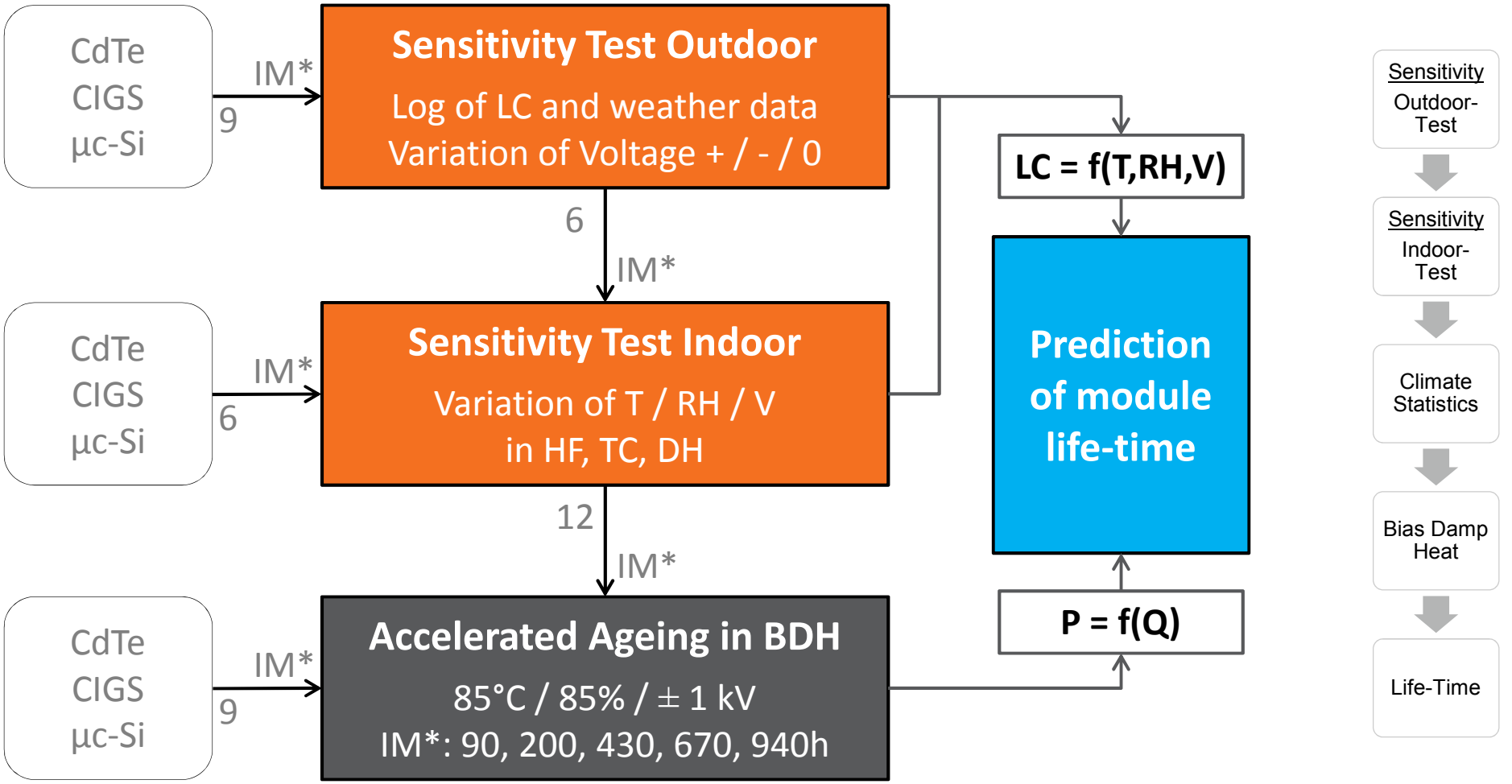


5) Life-Time Prediction
Test Sequence



IM* … Intermediate Power-Measurement, HF…Humidity Freeze, TC…Temperature-Cycle, DH…Damp-Heat, LC…Leakage-Current

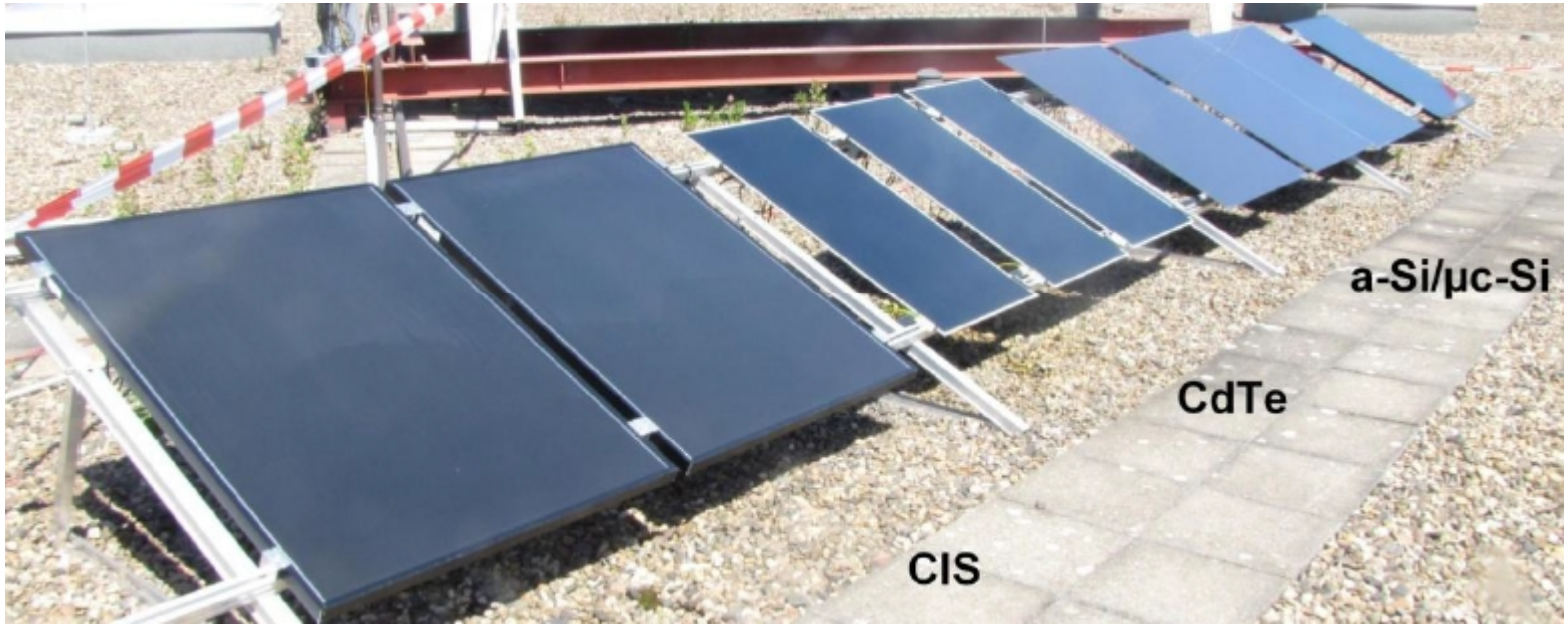
5) Life-Time Prediction
Test Sequence



IM* … Intermediate Power-Measurement, HF…Humidity Freeze, TC…Temperature-Cycle, DH…Damp-Heat, LC…Leakage-Current

5) Life-Time Prediction
Outdoor Test

- Outdoor-Test:
  - 4 weeks in June 2013 at PI-Berlin‘s Outdoor Test Facitity
  - Log of: weather data, leakage currents, module temperature



Sensitivity Outdoor-Test

Sensitivity Indoor-Test

Climatic Statistic

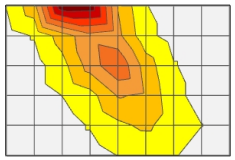
Bias Damp Heat

Life-Time

→Aim: **collection of all parameter spaces** (Temp. and RH) for one year and a representative leakage current

→ outdoor data (95%) completed by indoor results (5%)

5) Life-Time Prediction
Climatic Statistic - one year in Berlin



Modul Temperature in °C

a)

Relative Humidity RH in %	< -10	-10-0	0-10	10-20	20-30	30-40	40-50	50-60	60-70	> 70
> 75	4	174	704	694	203	4	-	Hours of each parameter space		
65-75	-	7	155	274	237	29	-			
50-65	-	-	65	257	406	159	7	-	-	-
40-50	-	-	1	64	217	193	31	-	-	-
30-40	-	-	-	8	81	127	48	2	-	-
< 30	-	-	-	-	3	8	9	-	-	-

b)

Relative Humidity RH in %	< -10	-10-0	0-10	10-20	20-30	30-40	40-50	50-60	60-70	> 70
> 75	*0.018*	*0.036*	0.057	0.117	0.084	*1.600*	-	Leakage Current in µA, CIGS -1kV		
65-75	-	*0.036*	0.032	0.048	0.069	0.064	-			
50-65	-	-	0.014	0.021	0.034	0.032	0.047	-	-	-
40-50	-	-	0.007	0.009	0.016	0.017	0.021	-	-	-
30-40	-	-	-	0.004	0.008	0.011	0.012	0.017	-	-
< 30	-	-	-	-	0.004	0.005	*0.006*	-	-	-

c)

Relative Humidity RH in %	< -10	-10-0	0-10	10-20	20-30	30-40	40-50	50-60	60-70	> 70
> 75	0.000	0.023	0.143	0.292	0.062	0.023	-	Transferred Charge in As		
65-75	-	0.001	0.018	0.047	0.059	0.007	-			
50-65	-	-	0.003	0.019	0.050	0.019	0.001	-	-	-
40-50	-	-	0.000	0.002	0.013	0.011	0.002	-	-	-
30-40	-	-	-	0.000	0.002	0.005	0.002	0.000	-	-
< 30	-	-	-	-	0.000	0.000	0.000	-	-	-

Time [t] = hours

×

Current [ILC] = µA

=

Charge [Q] = As

Sensitivity Outdoor-Test

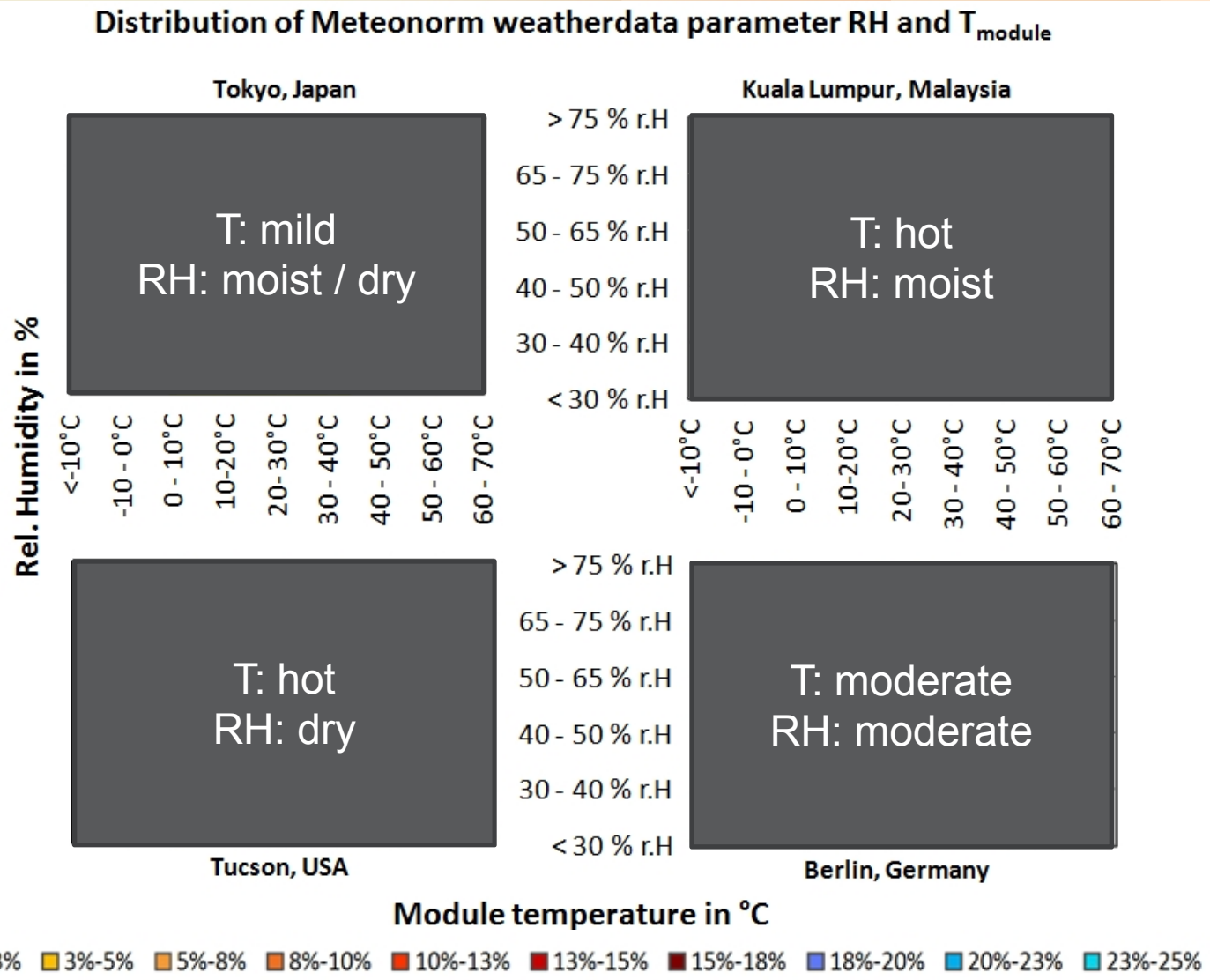
Sensitivity Indoor-Test

Climatic Statistic

Bias Damp Heat

Life-Time

5) Life-Time Prediction
Climatic Statistic - simulated Locations



Sensitivity Outdoor-Test

Sensitivity Indoor-Test

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Life-Time

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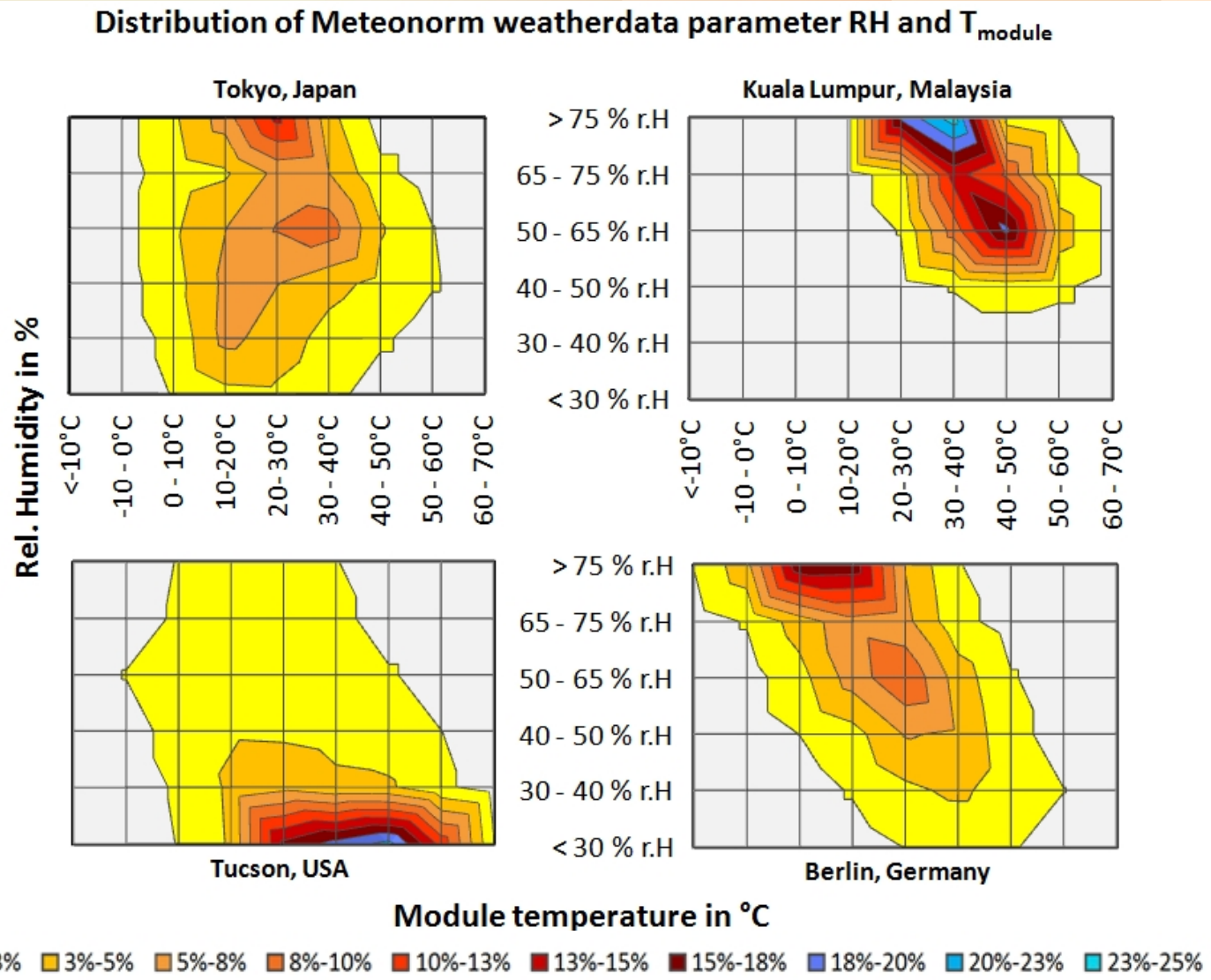


Sensitivity Outdoor-Test

Sensitivity Indoor-Test

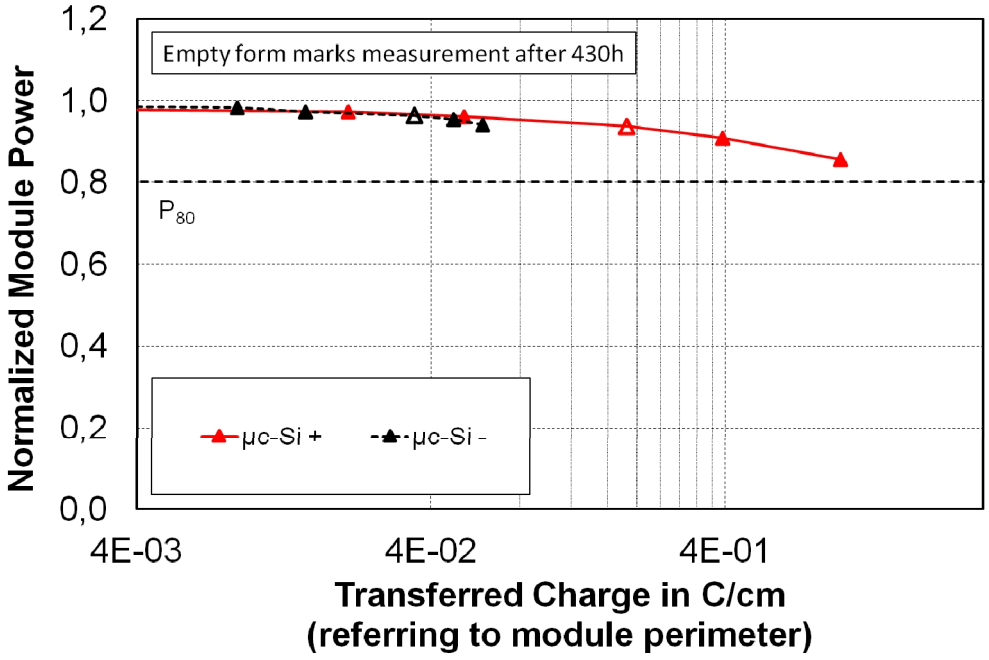
Climatic Statistic

Bias Damp Heat

Life-Time

5) Life-Time Prediction
Degradation-Experiment → P = f(Q)

- BDH-Experiment:
  - Intermediate measurements after 0, 90, 200, 430, 670, 940
  - **Fail criteria**: P_{80} … still 80% of initial power remaining
  - *Q(P80)* in some cases extrapolated



→ Result *Q(P80)*-value:

					µc-Si +	µc-Si -
Q(P80) in C/cm					1,4098	0,1550

Sensitivity Outdoor-Test
Sensitivity Indoor-Test
Climatic Statistic
Bias Damp Heat
Life-Time

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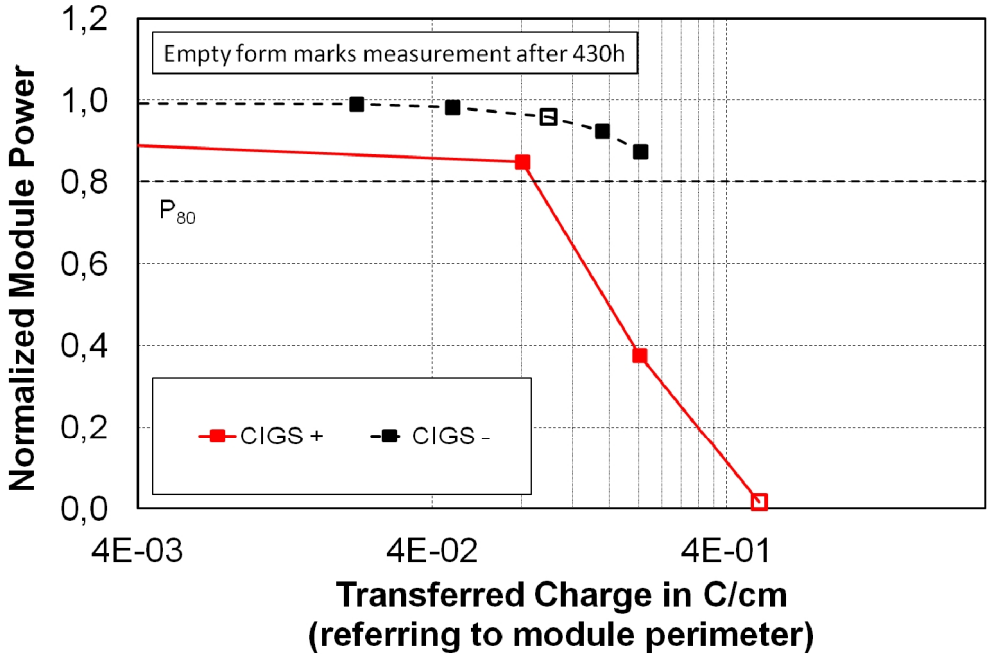

→ Result Q(P80)-value:

			CIGS +	CIGS -	µc-Si +	µc-Si -
$Q(P_{80})$ in C/cm			0,0933	0,2547	1,4098	0,1550

Sensitivity Outdoor-Test
→ Sensitivity Indoor-Test
→ Climatic Statistic
→ Bias Damp Heat
→ Life-Time

5) Life-Time Prediction
Degradation-Experiment P = f(Q)

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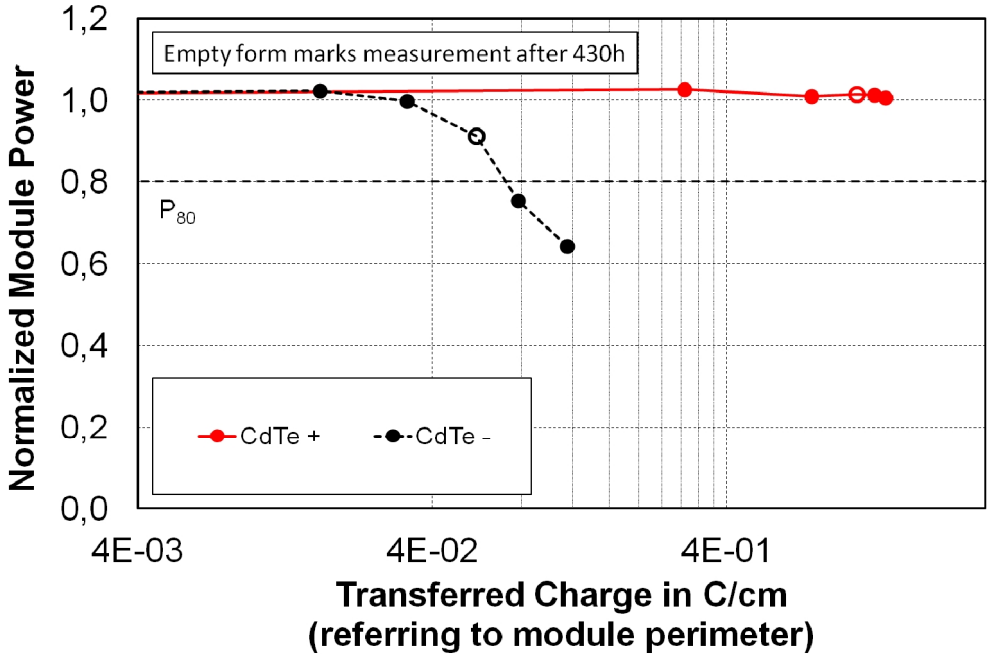


→ Result Q(P80)-value:

	CdTe +	CdTe -	CIGS +	CIGS -	µc-Si +	µc-Si -
$Q(P_{80})$ in C/cm	2,1466	0,0712	0,0933	0,2547	1,4098	0,1550

→ Amount of Charge till 20% of power are lost differ from module to module by more than three orders of magnitude

Sensitivity Outdoor-Test
Sensitivity Indoor-Test
Climatic Statistic
Bias Damp Heat
Life-Time

5) Life-Time Prediction
Merging all into Life-Times

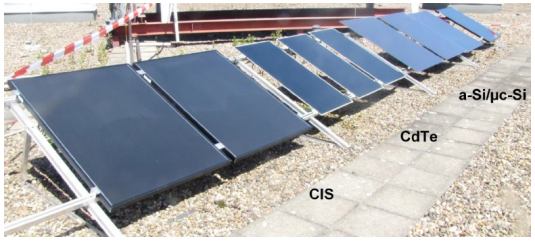
Sensitivity Outdoor-Test

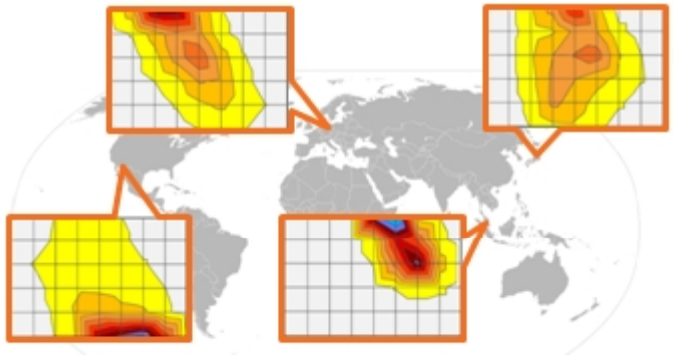
Sensitivity Indoor-Test

Climatic Statistic

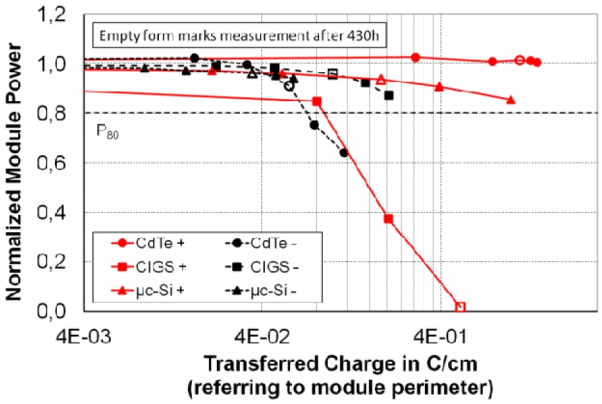
Bias Damp Heat

Life-Time





c)	<-10	-10-0	0-10	10-20	20-30	30-40	40-50	50-60	60-70	>70
>75	0,0003	0,0227	0,1433	0,2918	0,0615	0,0230	-	geflossene Ladung in C		
65-75	-	0,0009	0,0179	0,0469	0,0591	0,0067	-			
50-65	-	-	0,0032	0,0192	0,0504	0,0185	0,0012	-	-	-
40-50	-	-	0,0000	0,0021	0,0126	0,0115	0,0024	-	-	-
30-40	-	-	-	0,0001	0,0023	0,0052	0,0021	0,0001	-	-
<30	-	-	-	-	0,0000	0,0001	0,0002	-	-	-



Module	PID-Module Life-Time (LT) in years (Module LT maybe limited by other mechanisms)			
	Kuala Lumpur	Berlin	Tokyo	Tucson
CdTe +	83	166	183	362
CIGS +	9	41	37	127
µc-Si +	51	135	157	1659
CdTe -	3	8	10	31
CIGS -	13	141	77	637
µc-Si -	20	21	39	294

5) Life-Time Prediction

- Prediction of module Life-Times for specific locations

Module	PID-Module Life-Time (LT) in years (Module LT maybe limited by other mechanisms)			
	Kuala Lumpur	Berlin	Tokyo	Tucson
CdTe +	83	166	183	362
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CdTe -	3	8	10	31
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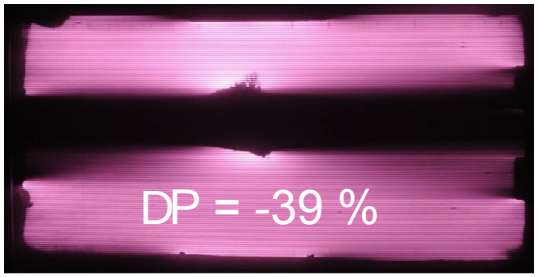
Classification of the Results (in years):
< 25 … PID critical
> 25 > 40 … likely PID uncritical
> 40 …means likely no PID

- The developed **Simulation Model for worst-case Analysis** enables:
  - Benchmarking
  - To exclude PID sensitive modules for PV projects
  - To determine the location-specific suitability of a technology
  - individual statement, if + or – system voltage is advantageous

6) Summary

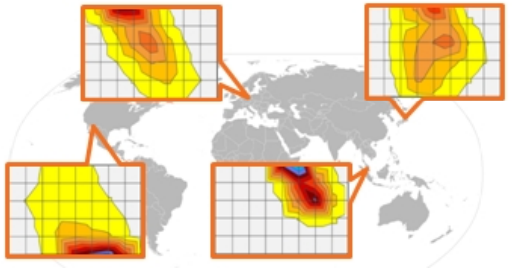
Lessons learned from PID-TF in general:

- Laboratory tests and field returns indicate **TF successability** to PID if module producer or EPC failed to adopt measurements to prevent PID



Life-Time Prediction:

- **Performing risk assessment** for a PV-plant in use or a PV-plant planned
- The developed **Simulation Model for worst-case Analysis**



Input for PI-Berlin

- We are requested as experts for TF degradation in the field with **laboratory tests** and **expert opinions.**

Modul	Modullebensdauer in Jahren			
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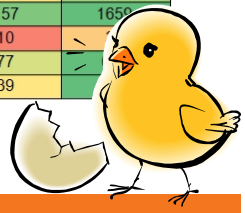
Thank You!



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Degradation-Experiment P = f(Q)

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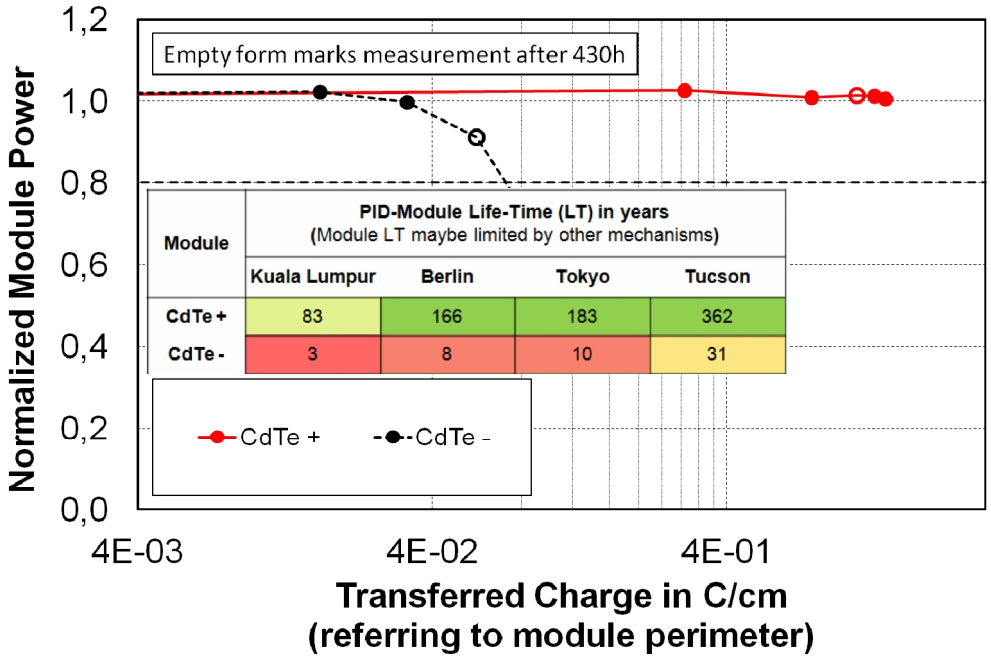

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→ Result Q(P80)-value:

	CdTe +	CdTe -				
$Q(P_{80})$ in C/cm	2,1466	0,0712				

Sensitivity Outdoor-Test
→ Sensitivity Indoor-Test
→ Climatic Statistic
→ **Bias Damp Heat**
→ Life-Time

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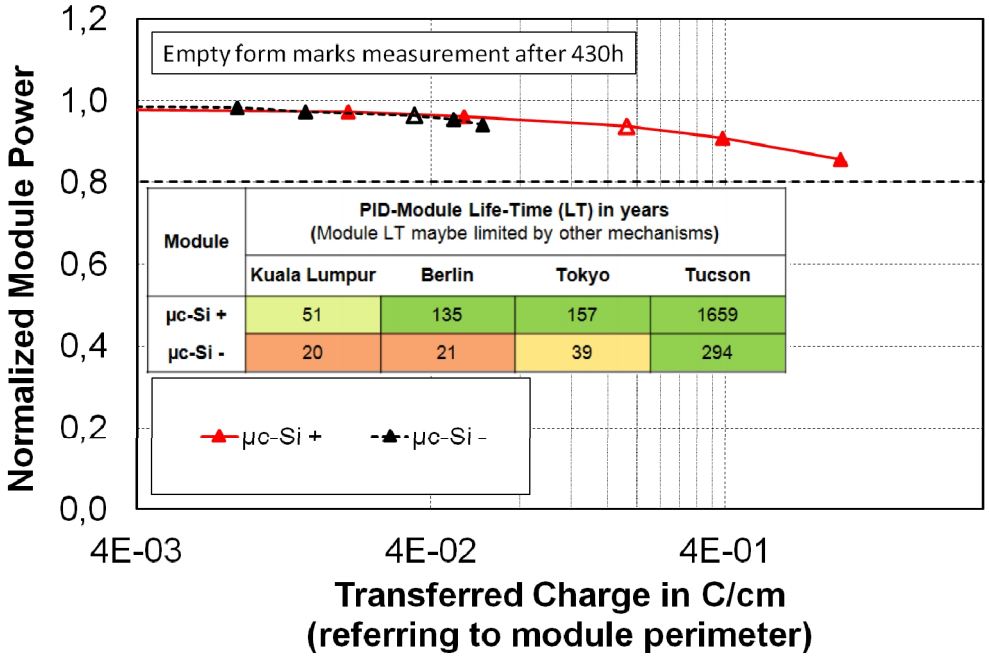

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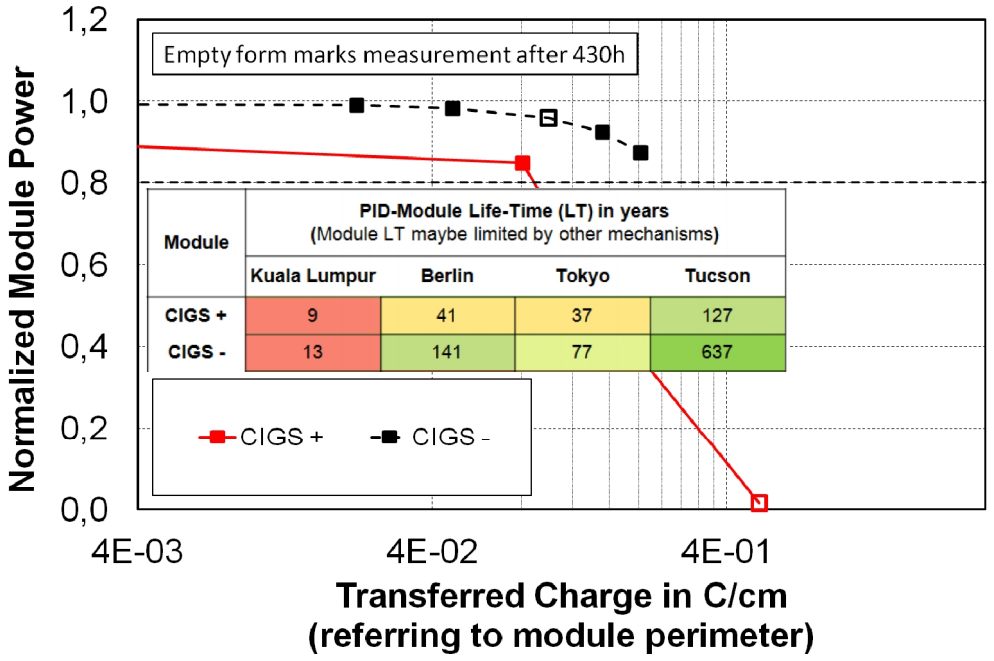

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→ Result Q(P80)-value:

			CIGS +	CIGS -		
$Q(P_{80})$ in C/cm			0,0933	0,2547		

Sensitivity Outdoor-Test
Sensitivity Indoor-Test
Climatic Statistic
Bias Damp Heat
Life-Time

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