IRENA & QUALITY INFRASTRUCTURE FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY IN LATIN AMERICA AND THE CARIBBEAN |
Forum on Regional Cooperation: Developing Quality Infrastructure for Photovoltaic Energy Generation | Santiago (CHILE) | Sep 12-13th 2017

Solar Bankability

Mitigating Technical Risks in PV Investment through Quality Infrastructure

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Funded by the Horizon 2020 Framework Programme of the European Union

www.solarbankability.eu

Shaping our world

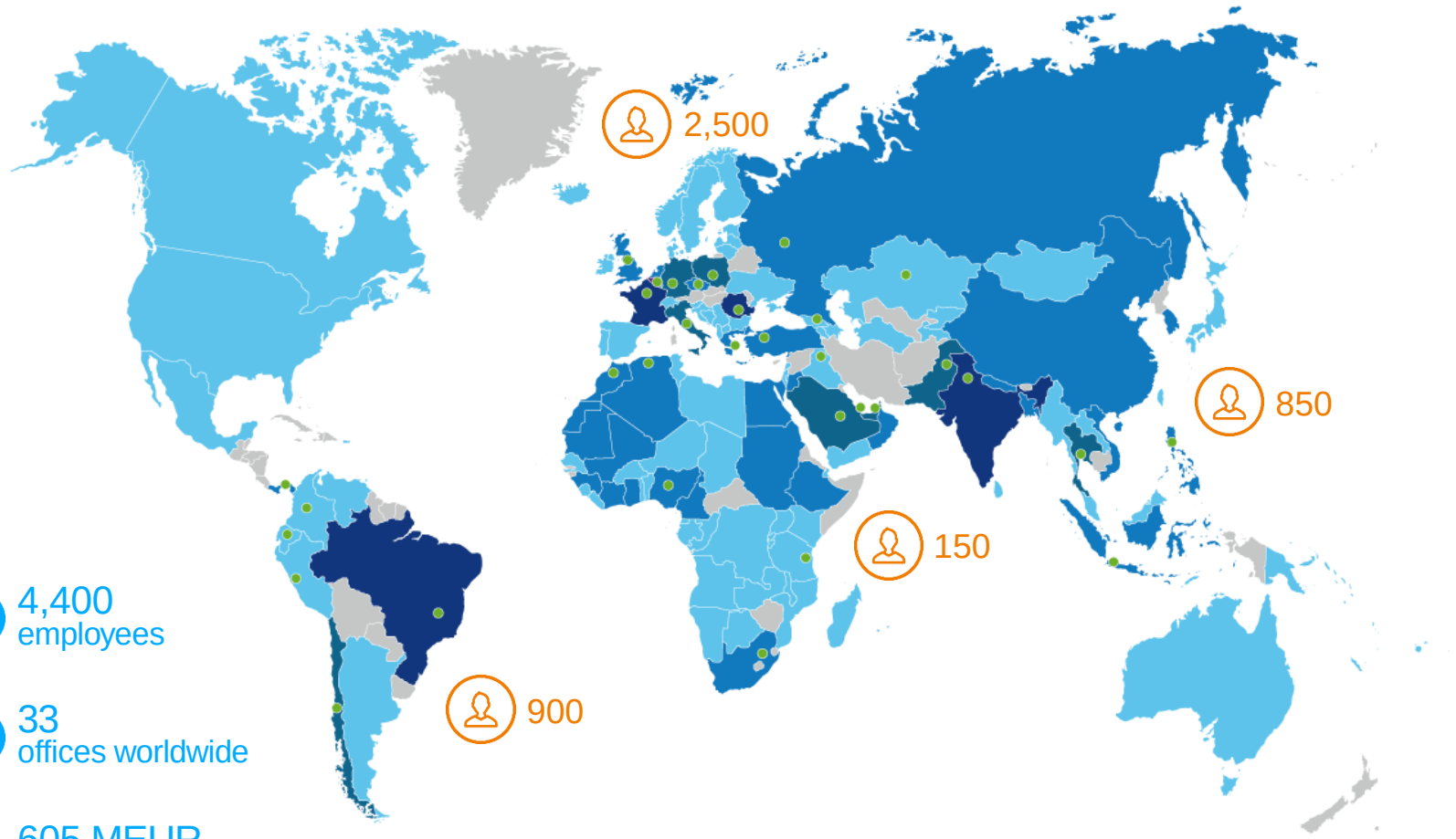
Together with our clients it's our mission to shape the world of tomorrow. Backed by 150 years of experience in energy, water and infra, we can provide you **engineering, consultancy and project management services** and be your partner in innovative solutions, the energy transition & digital transformation.

Daniel Develay, CEO

TRACTEBEL

ENGIE

Wherever you are located



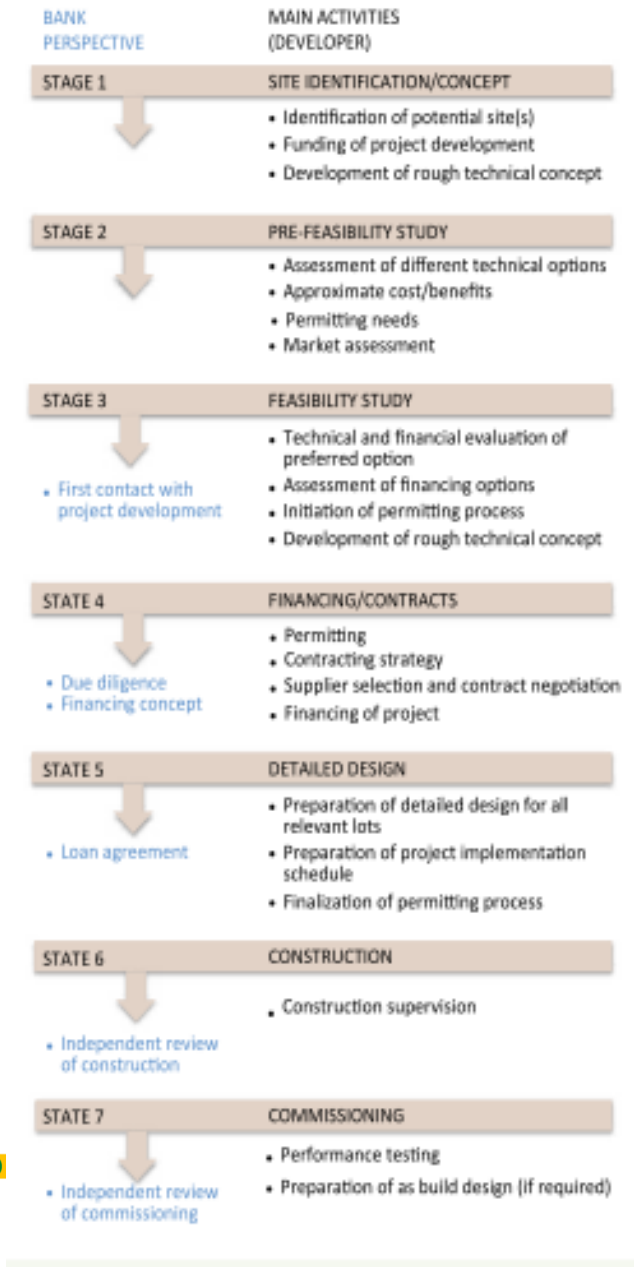
4,400
employees

33
offices worldwide

605 MEUR
turnover

Solar PV – Scope of services

- Tractebel can provide Technical Advisory & Owner's Engineer services at all stages of project development covering
  - Concept / basic / detailed design
  - Solar Resource Assessment & Energy Yield Assessment
  - Grid connection, grid impact and grid code compliance studies
  - Permitting assistance, ESIA
  - Tendering and contracting
  - Construction & commissioning follow-up
- Tractebel can team-up with legal and financial advisors where required



Solar Bankability Project Overview

- Objective:

  Improving the **finance-ability** and **attractiveness** of PV investments through common **tools and best-practice guidelines** for **professional risk assessment** which will serve to reduce the technical risks associated with investments in PV projects

- Funded by European Union Horizon 2020 Work Programme
- March 2015 – February 2017
- 5 consortium partners: 3E (BE), Accelios Solar (DE), EURAC Research (IT), SolarPower Europe (BE), TUV Rheinland (DE)

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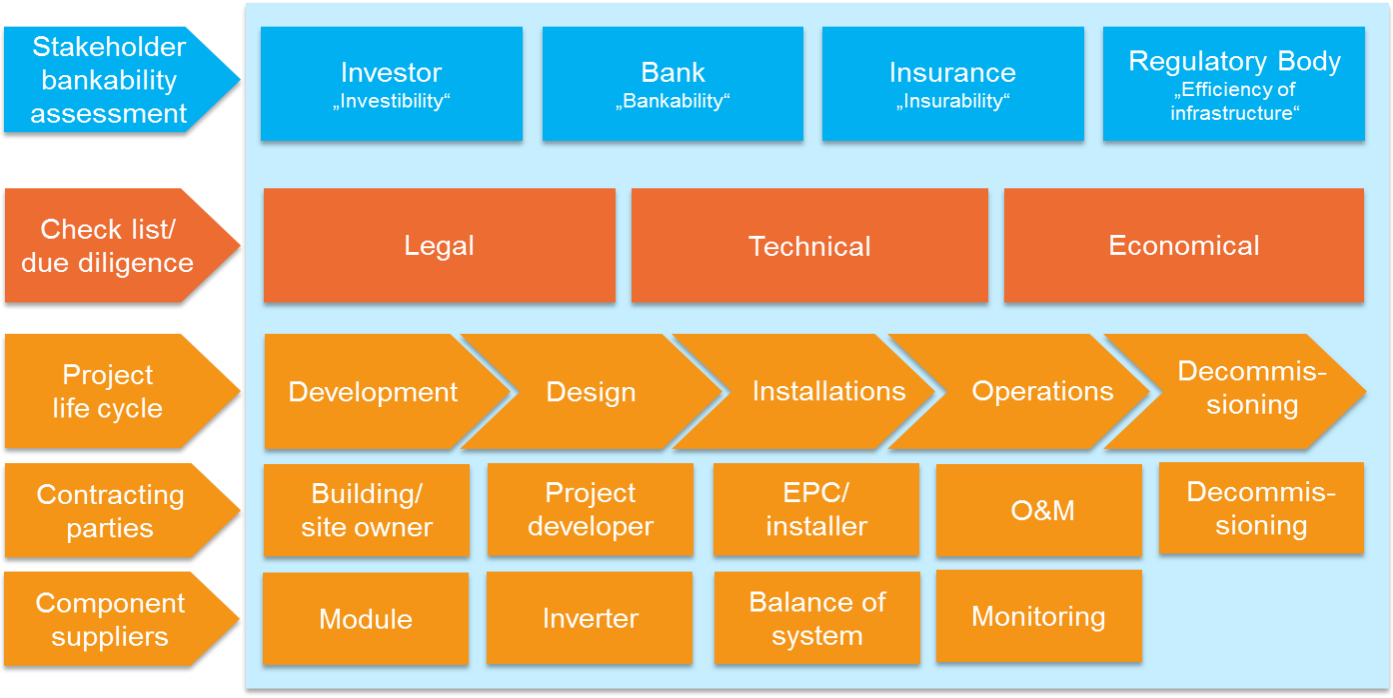
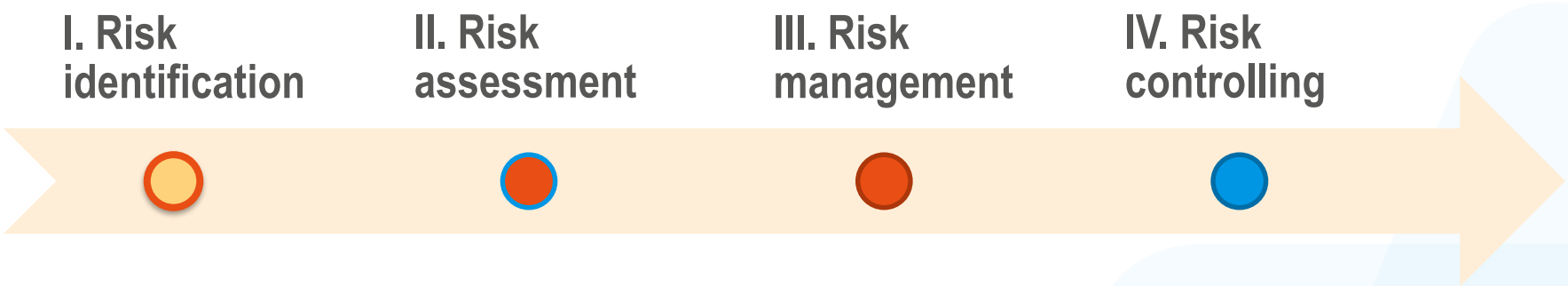
Bankability of PV Project

- Solar bankability: active quality management process where all stakeholders in PV project approval process attempt to identify, manage and control potential risks (technical, legal & economical) through entire project lifecycle
- Different stakeholders → different focus



Risk Management Framework



- Solar Bankability has developed a set of **useful tools and best-practice guidelines** for professional risk assessment and management in PV investment:
  - De-risking tools to reduce technical risks
  - Standardization tools as common approach for risk assessment

(I) Risk Identification

Risk identification | Risk assessment | Risk management | Risk controlling

Two tools to help identify PV investment technical risks:

1. Top 20 LCOE technical risks

- most common 20 incorrect technical assumptions in calculating PV LCOE

2. Technical risk matrix

- database of PV plant failures

(I) Risk Identification – Common LCOE Technical Risks

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Risk	Phase/field	Identified critical technical gaps
Year-0	Procurement/ product selection and testing	1. Insufficient EPC technical specifications to ensure that selected components are suitable for use in the specific PV plant environment of application. 2. Inadequate component testing to check for product manufacturing deviations. 3. Absence of adequate independent product delivery acceptance test and criteria.
	Planning/ lifetime energy yield estimation	4. The effect of long-term trends in the solar resource is not fully accounted for. 5. Exceedance probabilities (e.g. P90) are often calculated for risk assessment assuming a normal distribution for all elements contributing to the overall uncertainty. 6. Incorrect degradation rate and behavior over time assumed in the yield estimation. 7. Incorrect availability assumption to calculate the initial yield for project investment financial model (vs O&M plant availability guarantee).
	Transportation	8. Absence of standardized transportation and handling protocol.
	Installation/ construction	9. Inadequate quality procedures in component un-packaging and handling during construction by workers. 10. Missing intermediate construction monitoring.
	Installation/ provisional and final acceptance	11. Inadequate protocol or equipment for plant acceptance visual inspection. 12. Missing short-term performance (e.g. PR) check at provisional acceptance test, including proper correction for temperature and other losses. 13. Missing final performance check and guaranteed performance. 14. Incorrect or missing specification for collecting data for PR or availability evaluations: incorrect measurement sensor specification, incorrect irradiance threshold to define time window of PV operation for PR/availability calculation.
Risks during operation	Operation	15. Selected monitoring system is not capable of advanced fault detection and identification. 16. Inadequate or absence of devices for visual inspection to catch invisible defects/faults. 17. Missing guaranteed key performance indicators (PR, availability or energy yield). 18. Incorrect or missing specification for collecting data for PR or availability evaluations: incorrect measurement sensor specification, incorrect irradiance threshold to define time window of PV operation for PR/availability calculation.
	Maintenance	19. Missing or inadequate maintenance of the monitoring system. 20. Module cleaning missing or frequency too low.

Impact on installation quality

Impact on cash flow model

Impact on installation quality

Impact on risk/cost ownership

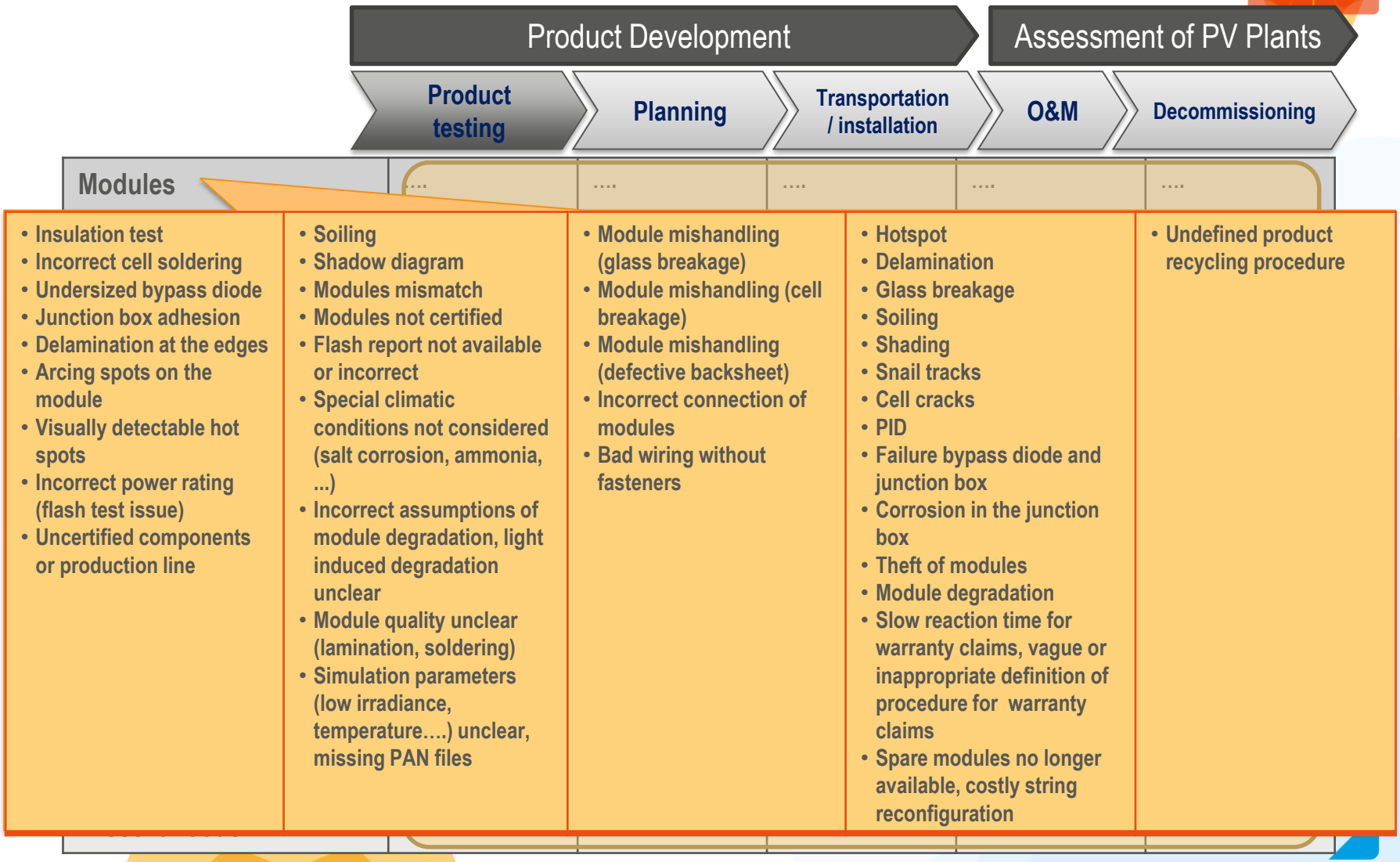
Impact on risk/cost ownership & O&M strategy

(I) Risk Identification – Database of PV Plant Failures

- Tickets from O&M operators from preventive and corrective maintenance
- Visual and detailed PV plant inspections

	Total number of plants	Total power [kWp]	Average number of years
TOTAL	**772**	**441,676**	**2.7**
Components	**No. of tickets**	**No. cases**	**No. of components**
Modules	473	678,801	2,058,721
Inverters	501	2,583	11,967
Mounting structures	420	16,147	43,916
Connection & distribution boxes	256	12,387	25,305
Cabling	682	384,600	246,084
Transformer station & MV/HV	57	224	759
TOTAL	**2,379**	**1,094,742**	**2,386,742**

(I) Risk Identification – Technical Risk Matrix



(II) Risk Assessment

Risk identification | **Risk assessment** | Risk management | Risk controlling

Three tools to assess technical risk impacts:

1. CPN methodology

- assess economic impacts of technical risks on PV plant operation

2. LCOE sensitivity analysis excel tool

- assess impacts of technical risks on PV LCOE

3. Cash flow risk categorization

- assess impacts of technical risks on PV business models

(II) Risk Assessment – Quantifying Economic Impacts

Planning during development phase

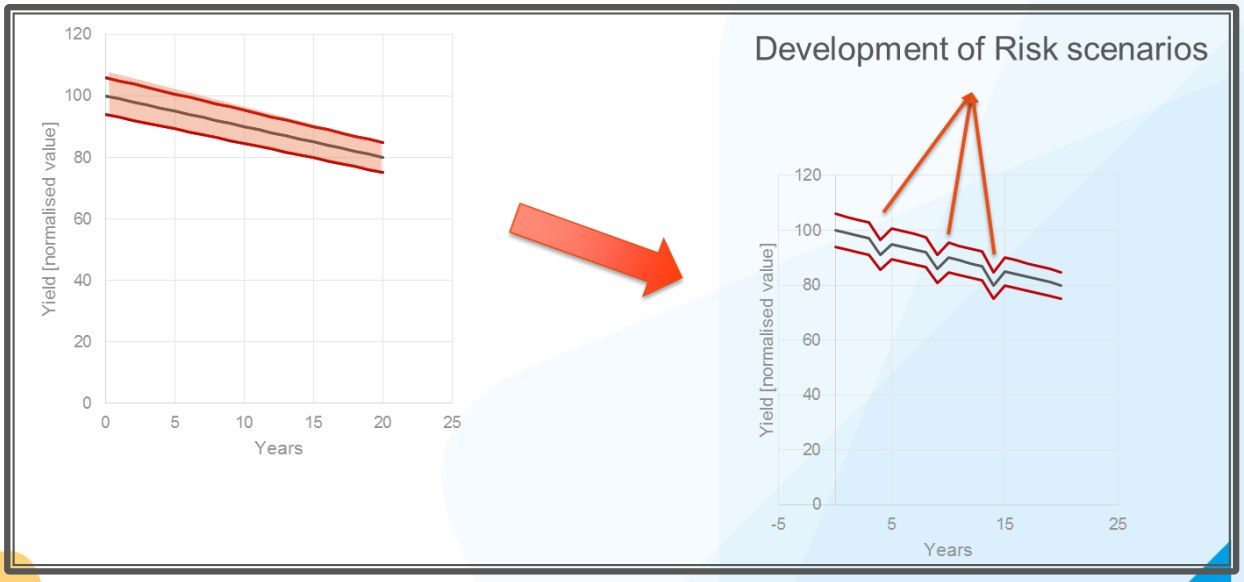
Risks to which we assign uncertainty

→ Impact on financial exceedance probability parameters

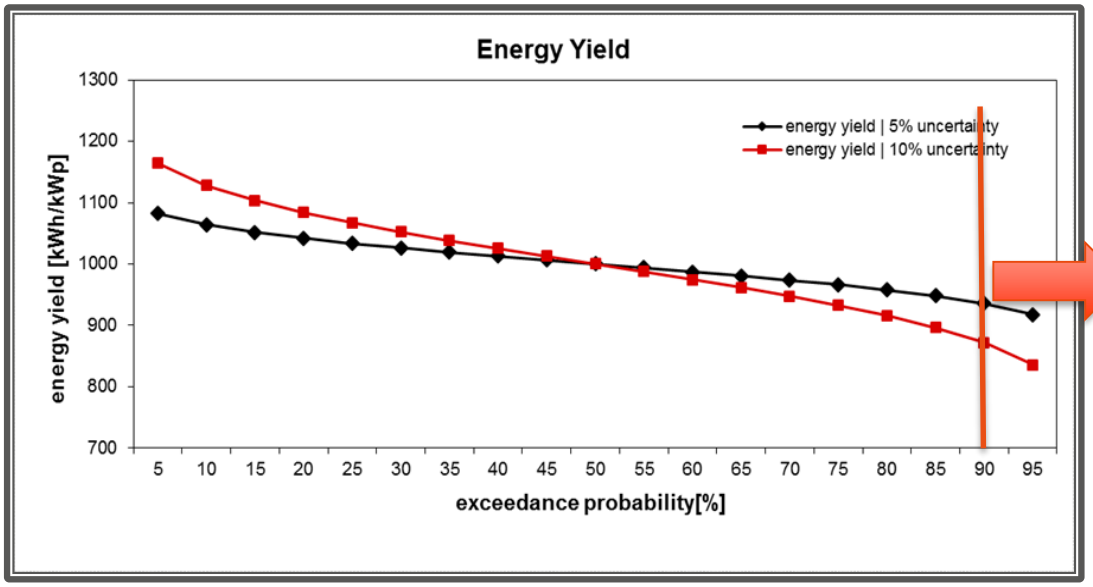
O&M phase

Risks to which we assign economic value (€/kWp/yr)

→ Impact on cash flow



(II) Risk Assessment – Uncertainties during Planning



Utilization rate @P90 positively affected by reduction in uncertainty

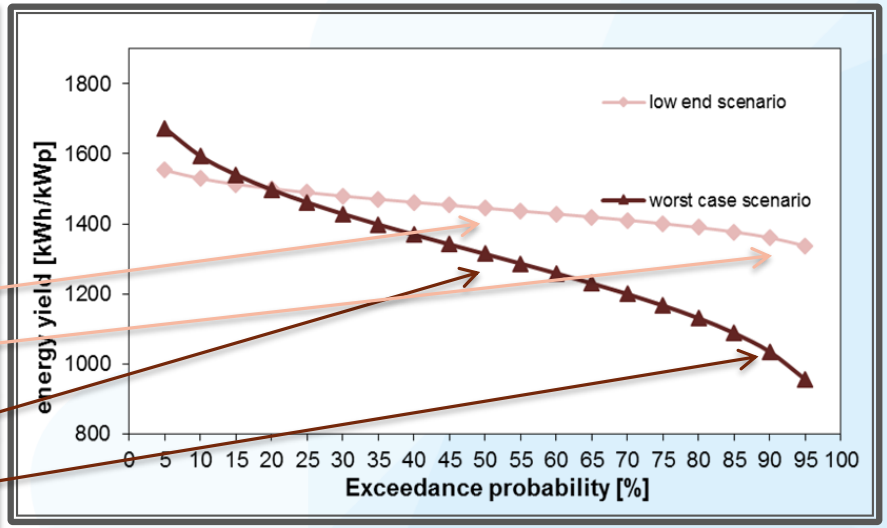
Link with business models and LCOE calculation

Typical uncertainty values (irradiance, temperature, soiling, shading, etc.) = 5-10%

(II) Risk Assessment – Improving Uncertainties

- Exceedance probabilities obtained by assuming normal distribution when calculating different uncertainties from dataset
- More precise estimation of uncertainty in yield estimation to reduce uncertainties
  - **Using empirically established probability distribution instead**
  - Challenge: need sufficiently large dataset!

	σ (k=1)	P50 (kWh/kWp)	P90 (kWh/kWp)	P90/P50 (P50 ref. case)
Reference case (PVSYST, not all contributions included)	**4.3%**	**1440**	**1360**	**94%**
Ref. case (sum of squares)	**8.7%**	**1445**	**1283**	**89%**
Low end scenario	4.6%	1445	1365	94%
High end scenario	9.3%	1445	1273	88%
Worst case scenario	16.6%	1445	1138	79%
Worst case scenario (different mean value)	16.6%	1314	1034	72%



22% difference in yield used in the business model !

(II) Risk Assessment – Quantifying Economic Impacts during Plant Operation

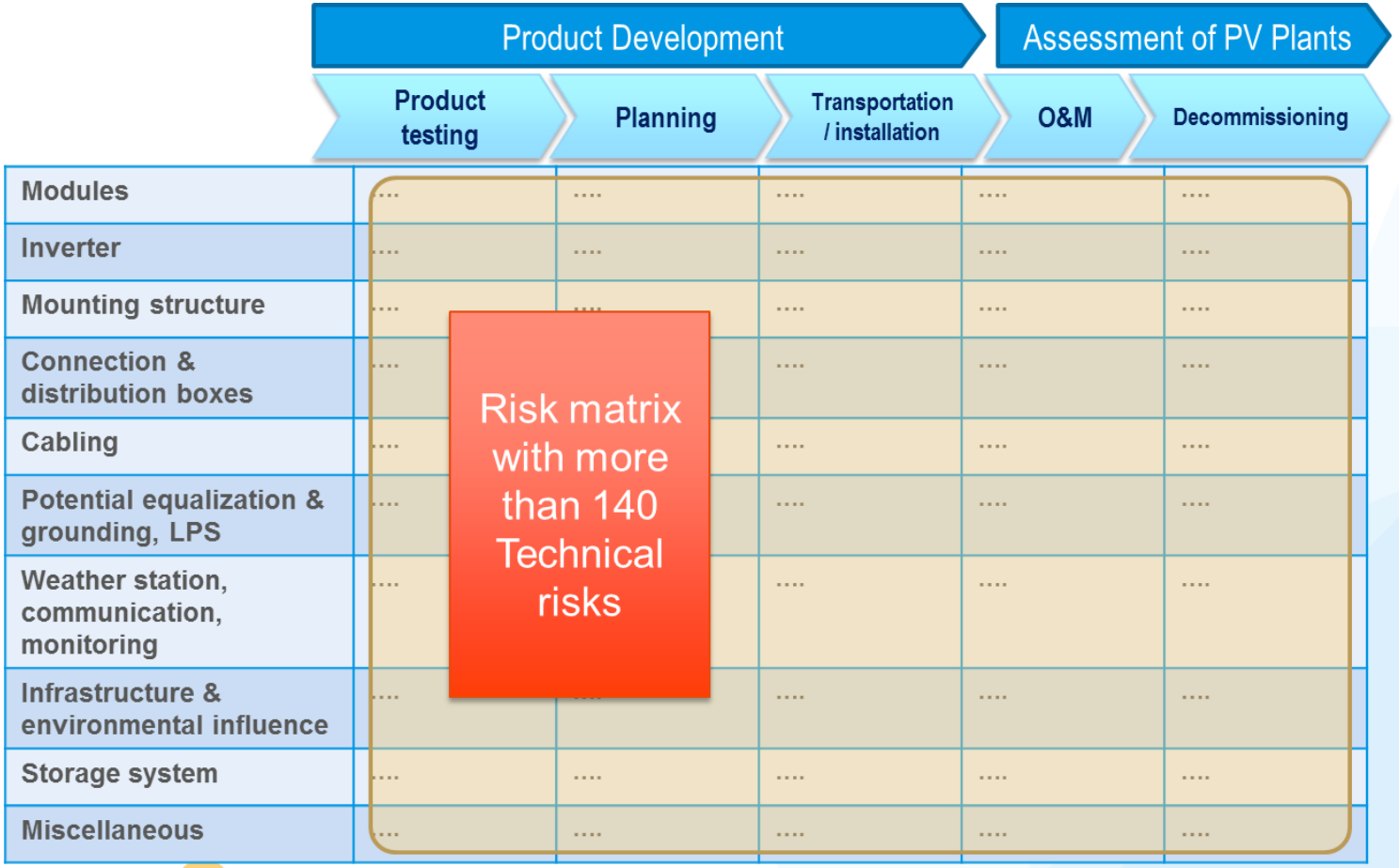
Cost Priority Number – new methodology!

- gives an indication of economic impacts of a failure due to **downtime** and **fixing cost**

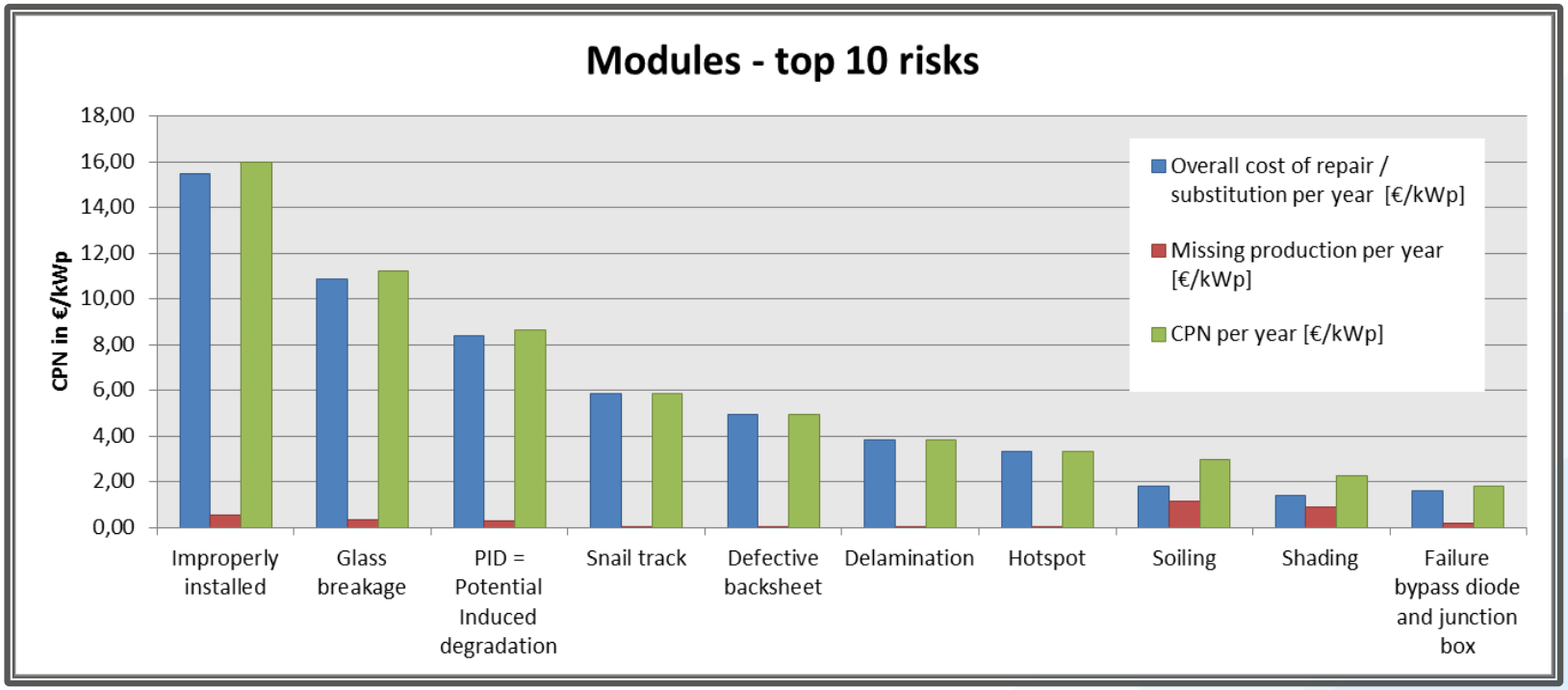
- Reduce income
- Reduce savings

- Increase maintenance costs
- Reduction of reserves

(II) Risk Assessment – CPN Analysis of Failures in Risk Matrix



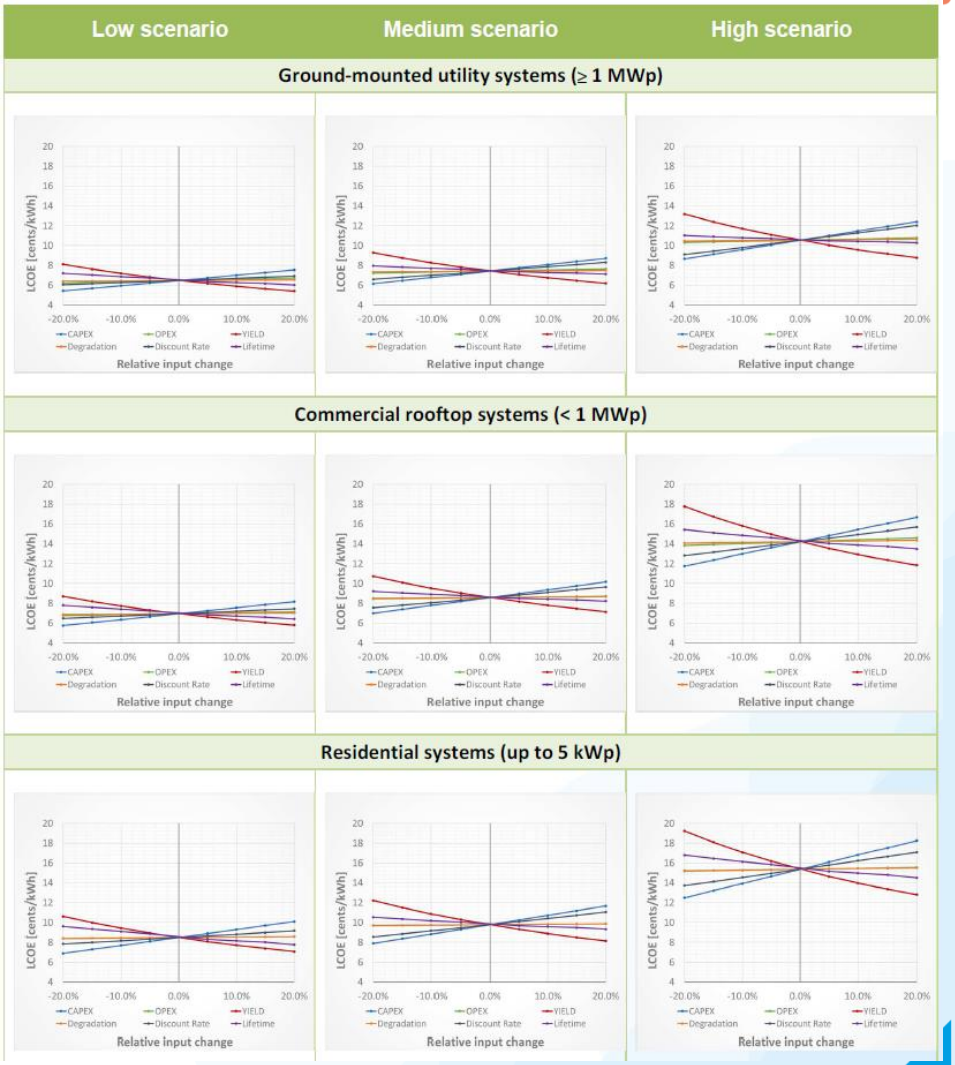
(II) Risk Assessment – e.g. CPN Ranked PV Module Failures (Utility Scale)



- Installation failures dominant (mishandling, connection failures, missing fixation, etc.)
- Variety of failures detected by different techniques (VI, IR, EL, IV-curve tracing)

(II) Risk Assessment – Impacts on LCOE

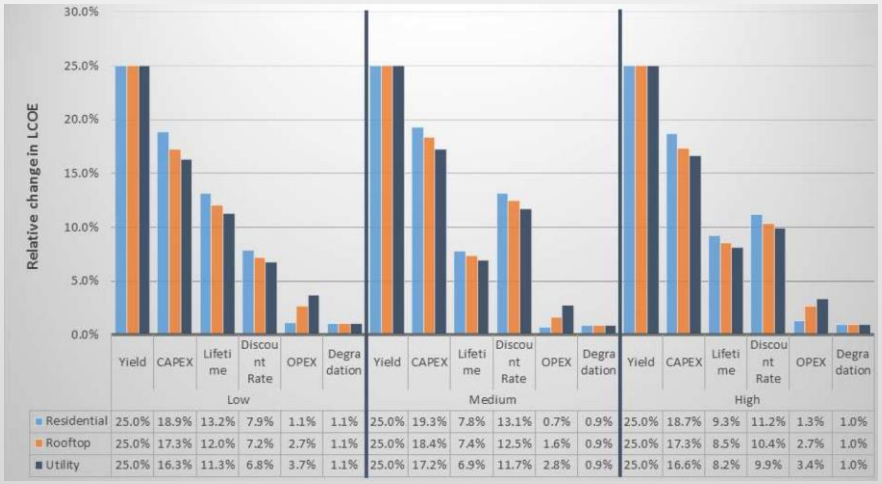
- Sensitivity analysis by varying LCOE inputs by ±20%
  - 3 market segments
  - 3 scenarios of CAPEX + OPEX (low, medium, high)



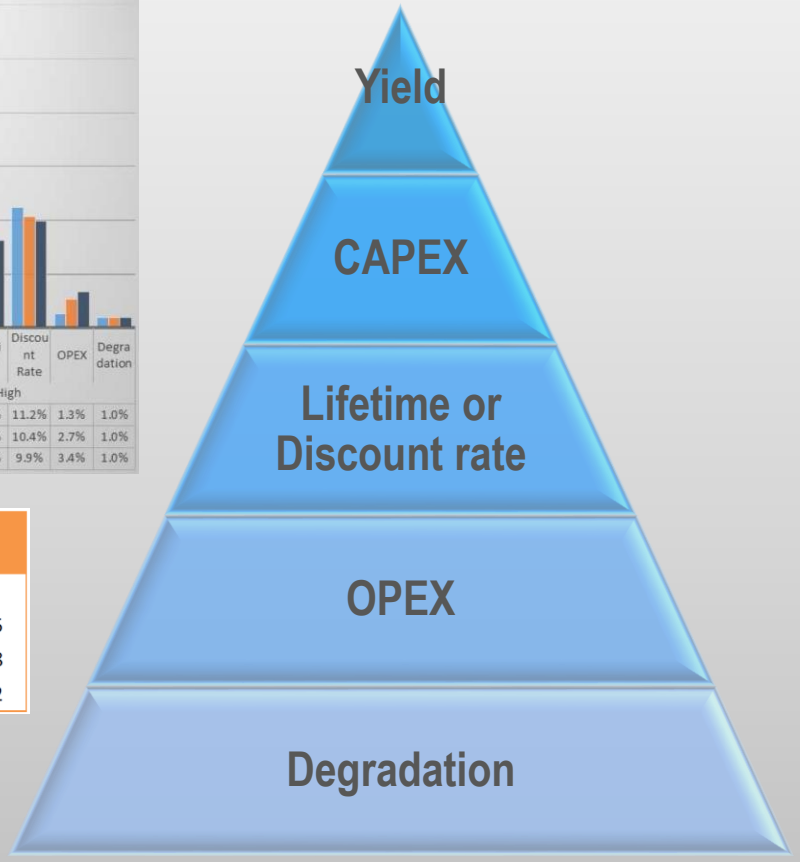
LCOE calculation excel tool *available for public download on project website*

(II) Risk Assessment – LCOE Sensitivity Ranking

Sensitivity of LCOE in 2015-2016 on its input parameters



Market segment	Low scenario	Medium scenario	High scenario
LCOE without any mitigation	*[€cents/kWh]*	*[€cents/kWh]*	*[€cents/kWh]*
Ground-mounted utility (≥ 1 MWp)	5.4 – 8.1	6.2 – 9.3	10.3 – 15.5
Commercial rooftop (< 1 MWp)	5.8 – 8.7	7.0 – 10.7	11.8 – 17.8
Residential (up to 5 kWp)	6.9 – 10.6	7.9 – 12.2	12.5 – 19.2



(II) Risk Assessment – Impacts on Business Model

- Modelling economic impact of technical risks on PV project cash flow requires:
  - Select business model to use
  - Identify associated technical risks
  - Determine likely risk scenario
  - Taking assumptions of underlying costs

- Case studies in Solar Bankability:
  1. 4 business models
  2. Introduce risk scenario
  3. Simulation using in-house developed financial modelling software
  4. Assess impacts on 12-month revenue

(II) Risk Assessment – Case Studies for Risk Impacts on Business Model

4 business models

		Description
Residential	Business model 1	Residential rooftop PV system with crystalline modules located in central Europe (5,6 kW, c-Si, Germany)
	Business model 2	Residential rooftop PV system with crystalline modules and battery storage located in central Europe (5,2 kW c-Si + storage, Germany)
Utility scale	Business model 3	Utility scale ground mounted PV system with crystalline modules, central inverters, located in northern Europe (7,6 MW, c-Si, UK)
	Business model 4	Utility scale ground mounted PV system with CdTe modules, string inverters, located in southern Europe (0,6 MW, CdTe, Italy)

Introduce up to 4 technical risks: 2 from technical risk matrix + 2 generic technical risks

Top 10 generic technical risks

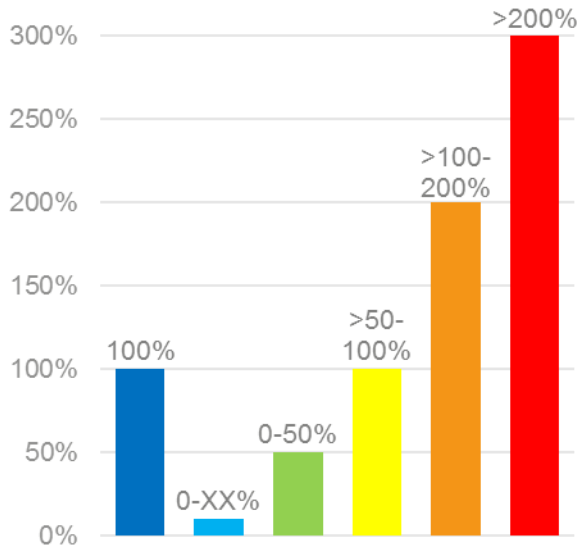
Number	Component	Name	BM1	BM2	BM3	BM4
Risk xx00	Module (C-Si)	Potential induced degradation (PID)	x	x	x	1)
Risk xx00	Module (CdTe)	Low Power/TCO corrosion				x
Risk xx10	Module	Failure of bypass diode/junction box	x	x	x	x
Risk xx20	Module	Hotspot	x	x	x	2)
Risk xx30	Module	Theft or vandalism	x	x	x	x
Risk xx40	Inverter	Fan failure and overheating	x	x	x	x
Risk xx50	Inverter	Lightning strike	x	x	x	x
Risk xx60	Mounting	Mismatch of module clamp	x	x	x	x
Risk xx70	Cable	UV aging of string cable	x	x	x	x
Risk xx80	Cable	Wrong/absent cable connection	x	x	x	x
Risk xx90	Cable	Cabling damaged by rodents	x	x	x	x

Selected technical risks by business model

Number	Component	Name	BM1	BM2	BM3	BM4
Risk 1100	Module	Glass breakage by hail	x			
Risk 1110	Module	Soiling of module	x			
Risk 2100	Battery	Failure of battery		x		
Risk 2110	Inverter	Failure of battery inverter		x		
Risk 3100	Inverter	Flooding of inverter			x	
Risk 3110	Module	Soling of module			x	
Risk 4100	Module	Glass breakage, frameless module				x

(II) Risk Assessment – Failure Categories

- The impact of risks is measured by failure categories based on a 12-month revenue



Reference base (100%): 12 months revenues from first calender year of full operations

Failure category 0 - (0-xx%): Regular operations and maintenance provisions

Failure category 1- (0-50%): Covered by 6 months reserve accounts

Failure category 2 - (>50-100%): Covered by 12 months reserve account

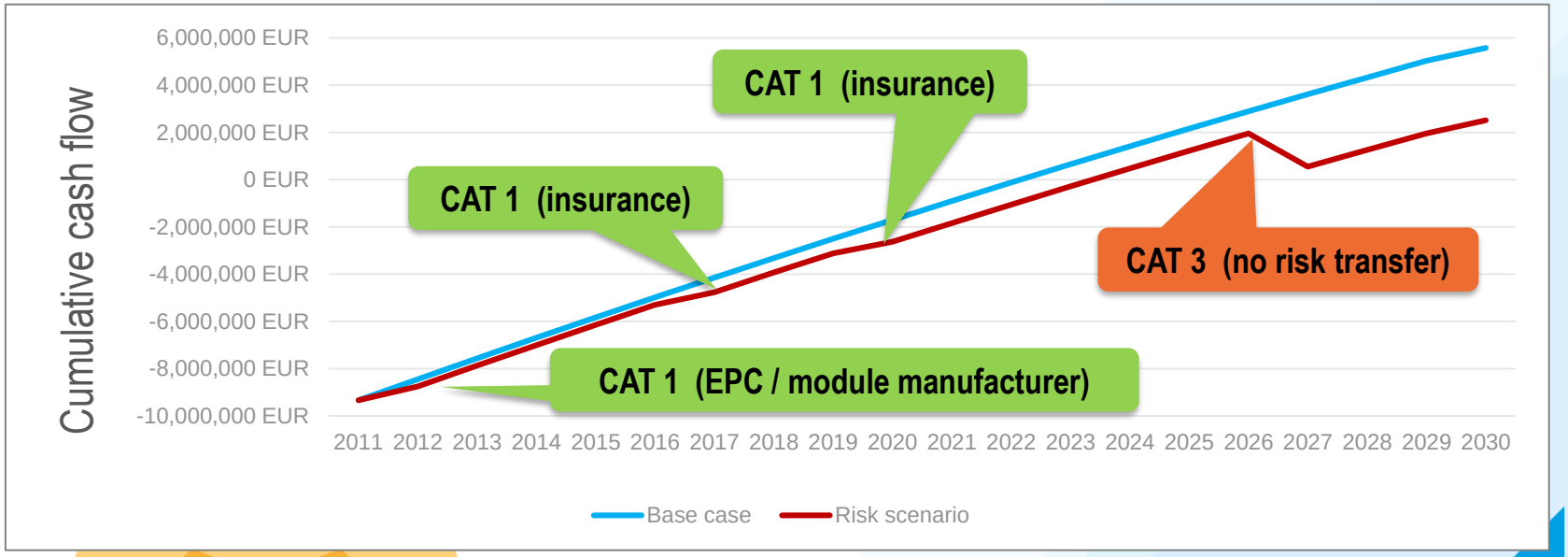
Failure category 3 - (>100-200%): Not covered by reserve account, potential need for additional equity

Failure category 4 - (>200%): Not covered by reserve account, potential need for additional equity capital

(II) Risk Assessment – Cash Flow Modelling of Technical Risk Impacts on Business Model #3 (example)

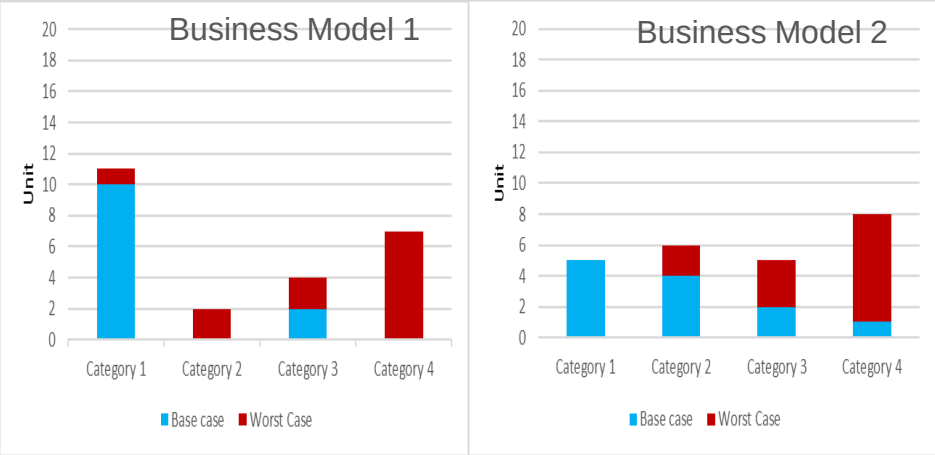
Risk scenario - business model 3					
Risk	**Risk number**	**Risk name**	**Start Date**	**Case**	**Phase**
Risk 1	3020	Hotspot of modules	01.01.2012	Best	Infant
Risk 2[2)]	3101	Flooding of inverter	01.08.2017	Worst	Mid-life
Risk 3[1)]	3051	Lightning strike of inverter	01.06.2020	Worst	Mid-life
Risk 4	3011	Failure of bypass diode and juction box	01.10.2026	Worst	Wear-out

Comments
1) External cause independent from project phase
2) Business model specific risk, i.e. due to system design/technology, geographic/climatic conditions

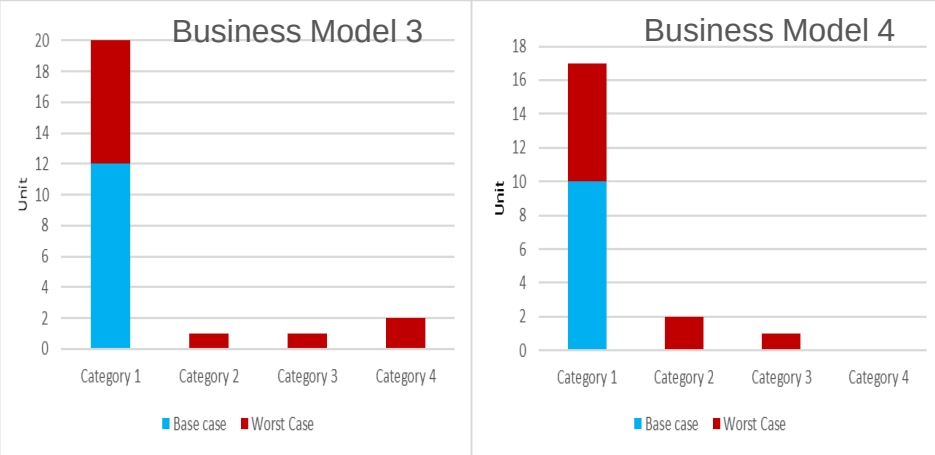


(II) Risk Assessment – Case Studies Results

Residential



Utility scale

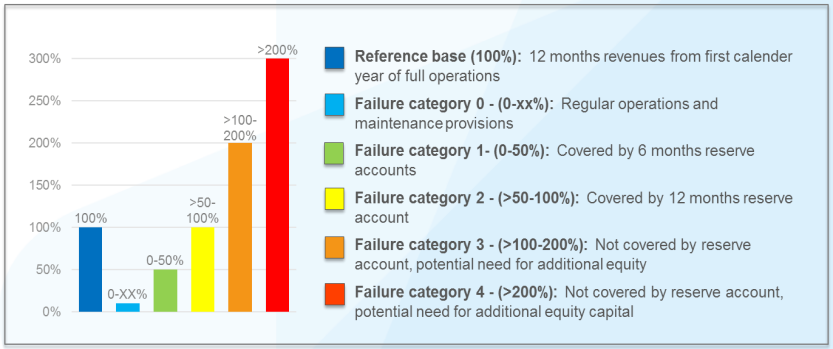


Residential-sized business models are most affected by impact of technical failures:

- Labor + spare parts costs + prolonged downtime costs due to missing monitoring systems

Utility PV system more robust:

- Online monitoring + O&M service contract → reduce downtime
- Economies of scale



(III) Risk Management

Risk identification | Risk assessment | **Risk management** | Risk controlling

Two tools to mitigate and manage technical risks:

1. List of mitigation measures

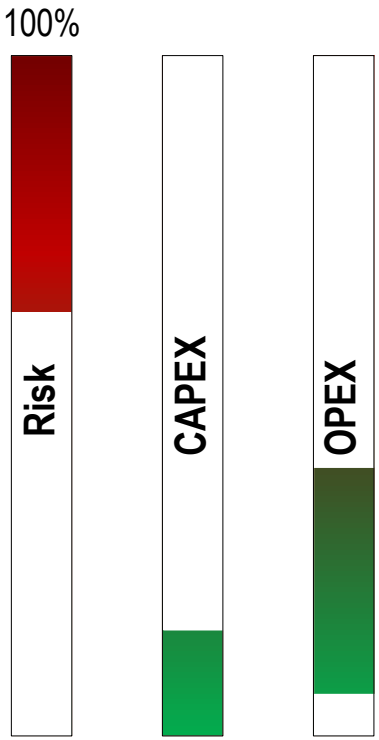
- recommended mitigation measures to manage common PV technical risks

2. Best practice guidelines

- 6 checklists as guidelines for best practices in EPC and O&M contract technical aspects

In addition to risk mitigation, **risk transfer** is also a risk management strategy!

(III) Risk Mitigation – Why & How



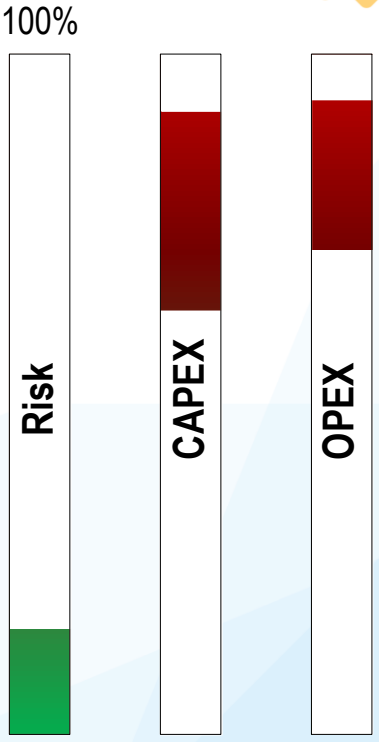
CAPEX & OPEX depending on mitigation measures

ΣCPNs = ~120€/kW/year

Who bears the cost?
Who bears the risk?

Risk minimization

ΣCPNs = ~XX €/kW/year



CAPEX & OPEX depending on mitigation measures

(III) Risk Mitigation Measures

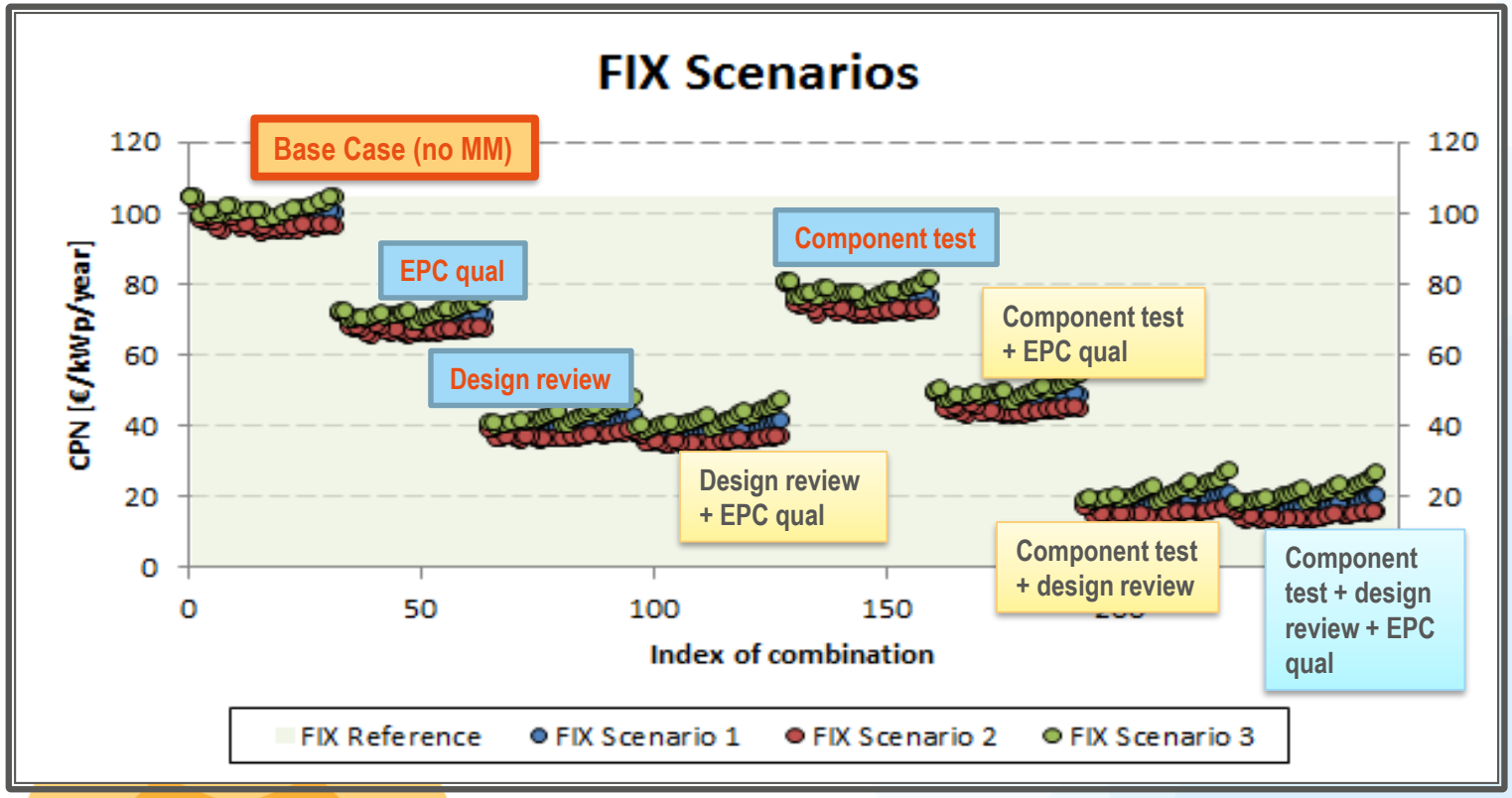
- 8 mitigation measures proposed based on analysis of technical failures in Risk Matrix

	Mitigation Measure	Improving	Costs (medium scenario)
Preventive measures (CAPEX)	Component testing – PV modules	number of failures	3 €/kWp
	Design review + construction monitoring	number of failures	20 €/kWp
	Qualification of EPC	number of failures	3 €/kWp
Corrective measures (OPEX)	Advanced monitoring system	time to detection	2 €/kWp/year
	Basic monitoring system	time to detection	0.5 €/kWp/year
	Advanced inspection	time to detection	2 €/kWp/year
	Visual inspection	time to detection	1 €/kWp/year
	Spare part management	time to repair/substitution	0.5 €/kWp/year

(III) Risk Mitigation Measures – Impacts on CPN

- Different combinations of 8 mitigation measures and resulting CPN

Preventive measures have higher impacts in reducing CPN, especially for poor quality plant.
For good quality plan, CPN helps to understand the impacts of corrective measures.



(III) Risk Mitigation Measures – Impacts on LCOE

- Different combinations of 8 mitigation measures and resulting LCOE
- Mitigation measures increases CAPEX and OPEX but also yield (utilization rate)!

Preventive measures have higher impacts in lowering LCOE

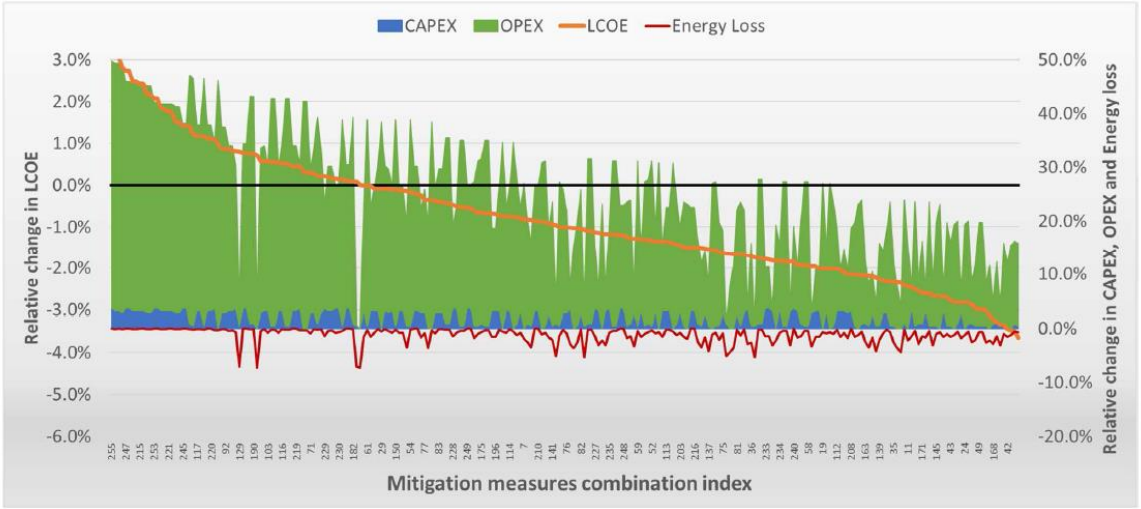
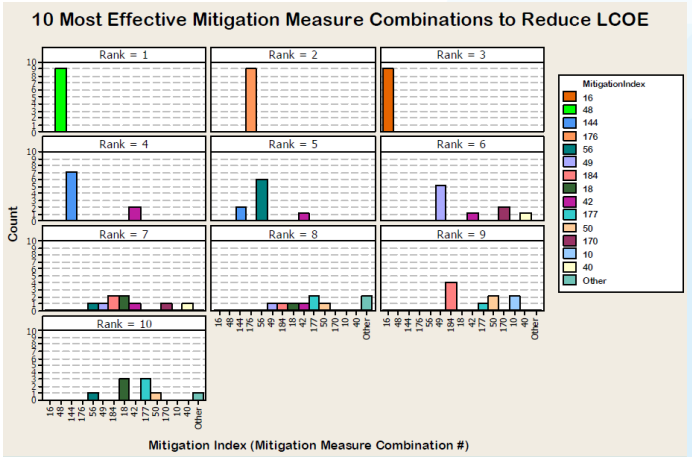


Figure 7: Sorted relative change in LCOE for 255 mitigation measure combinations for ground-mounted utility system for "low" scenario



Mitigation measures most effective in lowering PV LCOE are:

1. **Qualification of EPC;**
2. **Component testing prior to installation; and**
3. **Advanced monitoring system for early fault detection.**

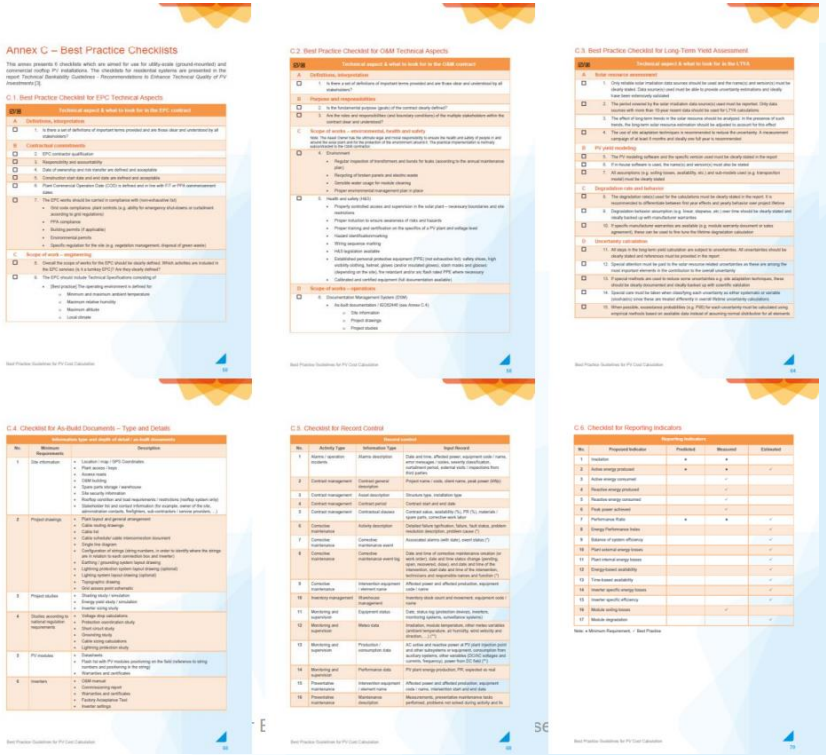
(III) Risk Mitigation Measures – LCOE after Mitigations Implementation

- 3.6 to 5.1% reduction in LCOE observed

Market segment	Low scenario	Medium scenario	High scenario
LCOE without any mitigation	*[€cents/kWh]*	*[€cents/kWh]*	*[€cents/kWh]*
Ground-mounted utility (≥ 1 MWp)	5.4 – 8.1	6.2 – 9.3	10.3 – 15.5
Commercial rooftop (< 1 MWp)	5.8 – 8.7	7.0 – 10.7	11.8 – 17.8
Residential (up to 5 kWp)	6.9 – 10.6	7.9 – 12.2	12.5 – 19.2
% maximum LCOE reduction			
Ground-mounted utility (≥ 1 MWp)	3.6%	3.8%	4.2%
Commercial rooftop (< 1 MWp)	4.6%	4.8%	5.0%
Residential (up to 5 kWp)	4.8%	5.0%	5.1%
LCOE after best mitigation combination	*[€cents/kWh]*	*[€cents/kWh]*	*[€cents/kWh]*
Ground-mounted utility (≥ 1 MWp)	5.2 – 7.8	5.9 – 8.9	9.9 – 14.8
Commercial rooftop (< 1 MWp)	5.5 – 8.4	6.7 – 10.3	11.2 – 17.0
Residential (up to 5 kWp)	6.6 – 10.1	7.5 – 11.6	11.9 – 18.2

(III) Risk Management – Best Practice Guidelines

1. Best practice checklist for EPC technical aspects
2. Best practice checklist for O&M technical aspects
3. Best practice checklist for long-term yield assessment
4. Checklist for as-built documents – types and details
5. Checklist for record control
6. Checklist for reporting indicators

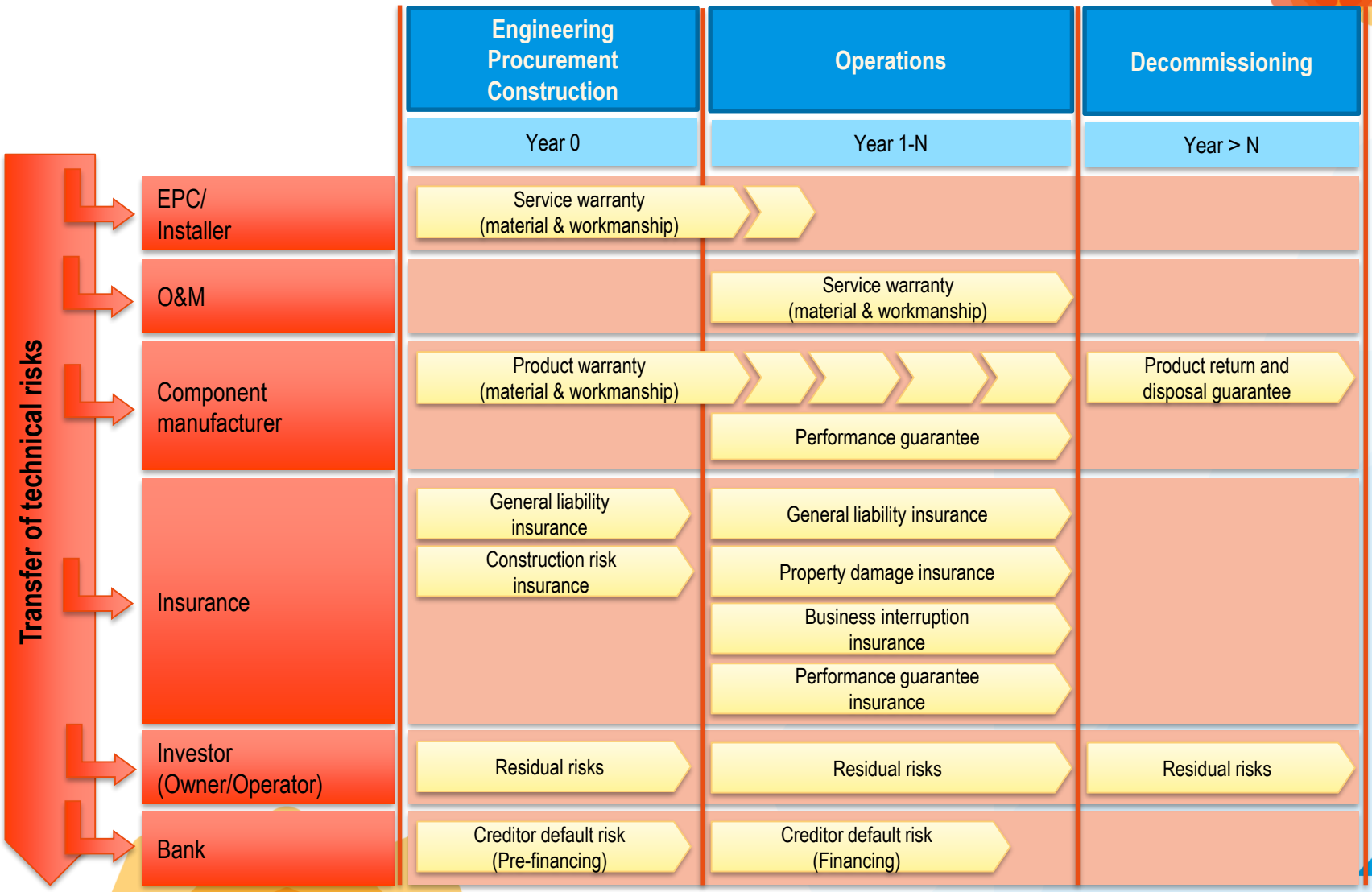


(III) Technical Aspects to Look for in EPC & O&M Contracts

EPC contract	
A	Definitions, interpretation
B	Contractual commitments
C	Scope of works – engineering
D	Scope of works – procurement
E	Scope of works – construction
F	Scope of works – administrative and others
G	Manufacturer warranties
H	EPC warranty and Defect Liability Period (DLP)
I	Key performance indicators (KPIs) and guarantees
J	Commissioning and acceptance

O&M contract	
A	Definitions, interpretation
B	Purpose and responsibilities
C	Scope of works – environmental, health and safety
D	Scope of works – operations
E	Scope of works – maintenance
F	Scope of works – data and monitoring
G	Scope of works – spare parts management
H	Scope of works – plant security
I	Key performance indicators (KPIs)
J	Contractual commitments

(III) Risk Transfer to Manage Risks



(IV) Risk Controlling

Risk identification | Risk assessment | Risk management | **Risk controlling**

Improve regulation in PV project financing:

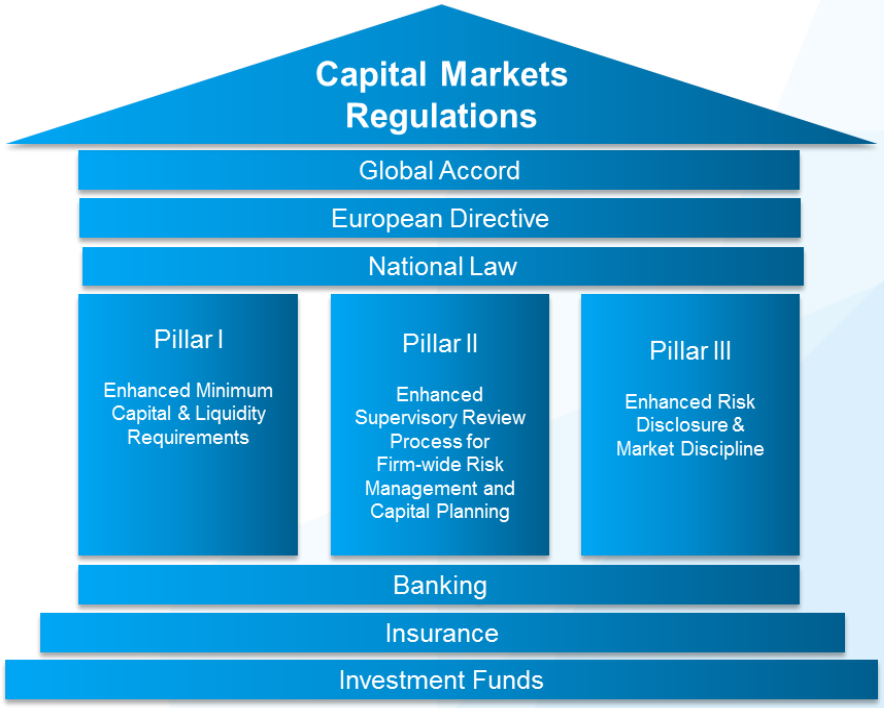
1. Financial market regulations

- improve transparency for institutional investors (banking – insurance – investment fund)

(IV) Risk Controlling – Capital Market Regulation

In a harmonized effort, financial regulatory bodies on a global, European and national level have developed a set of regulations for each capital market sector:

- Banking (Basel III)
- Insurance (Solvency II)
- Investment Funds (UCITS V / AIFM)



Solar Bankability

In summary …

Solar Bankability – Tools & Best-Practice Guidelines for Professional Risk Assessment & Management

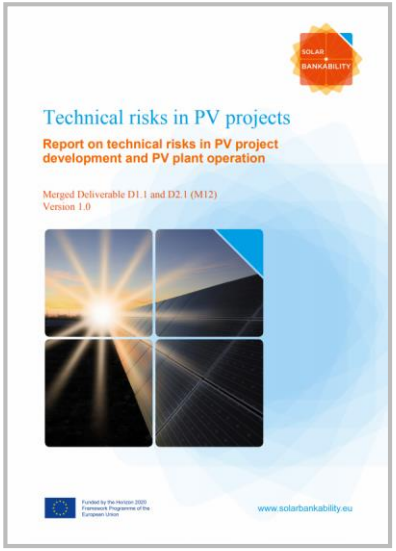
1. Top 20 LCOE technical risks
2. Technical risk matrix

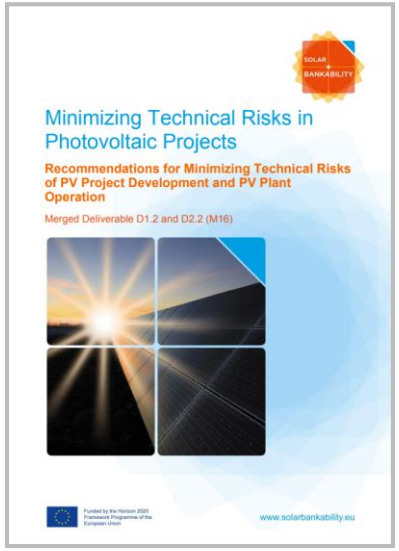
3. CPN methodology
4. LCOE sensitivity analysis excel tool
5. Cash flow risk categorization

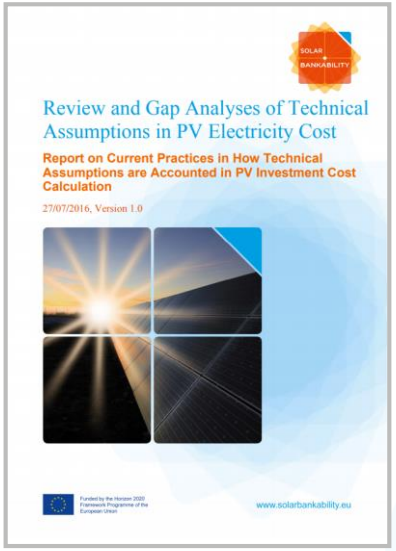
Capital market regulations

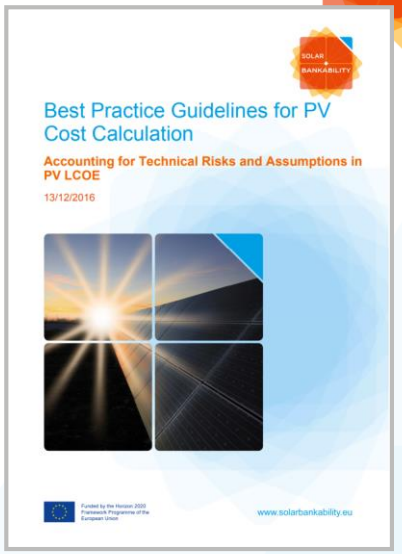
6. 8 mitigation measures
7. 6 best-practice checklists

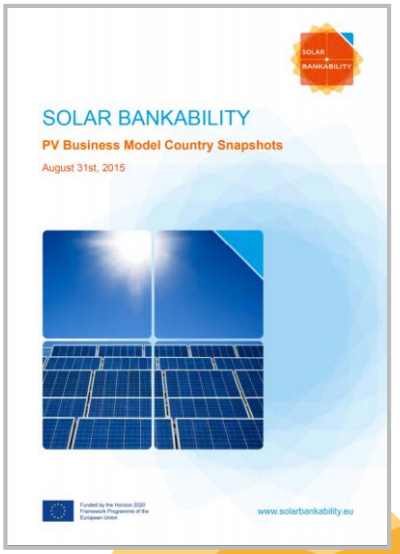
Project Reports: www.solarbankability.eu

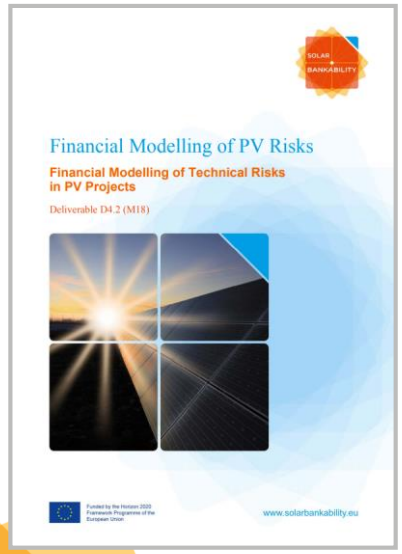


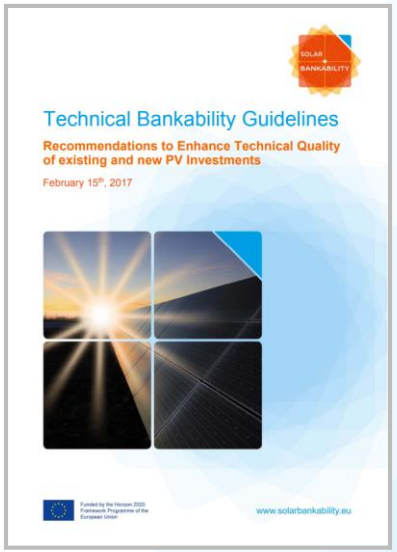


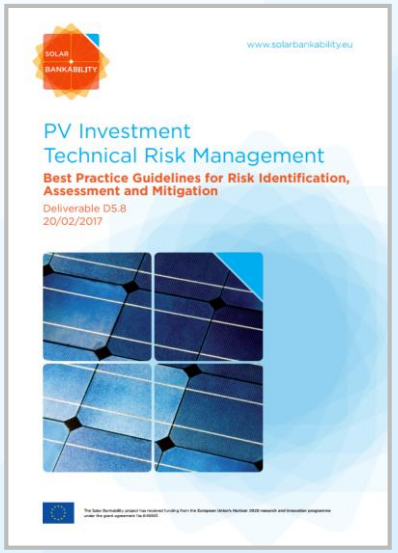












Thank you!

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