Solar Bankability
10/26/2016 Brussels (BE)

An Assessment of Technical Risks in PV Investments

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Funded by the Horizon 2020
Framework Programme of the
European Union

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Project Overview

- European Union Horizon 2020 Work Programme
- 24 months (March 2015 – February 2017)
- 5 consortium partners:

Main Objective: Develop and establish a common practice for professional risk assessment which will serve to reduce the technical risks associated with investments in PV projects.

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Technical Risks Matrix

	Product Development			Assessment of PV Plants	
	Product testing	Planning	Transportation / installation	O&M	Decommissioning
Modules	....	....	....	....	....
Inverter	....	....	....	....	....
Mounting structure	....	....	....	....	....
Connection & distribution boxes	....	....	....	....	....
Cabling	....	....	....	....	....
Potential equalization & grounding, LPS	....	....	....	....	....
Weather station, communication, monitoring	....	....	....	....	....
Infrastructure & environmental influence	....	....	....	....	....
Storage system	....	....	....	....	....
Miscellaneous	....	....	....	....	....

> 140 Risks

List of Module Risks

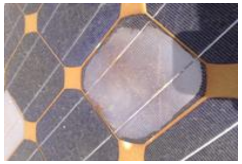
Product Development | Assessment of PV Plants

Modules

Product testing	Planning	Transportation / installation	O&M	Decommissioning
• Insulation test • Incorrect cell soldering • Undersized bypass diode • Junction box adhesion • Delamination at the edges • Arcing spots on the module • Visually detectable hot spots • Incorrect power rating (flash test issue) • Uncertified components or production line	• Soiling • Shadow diagram • Modules mismatch • Modules not certified • Flash report not available or incorrect • Special climatic conditions not considered (salt corrosion, ammonia, ...) • Incorrect assumptions of module degradation, light induced degradation unclear • Module quality unclear (lamination, soldering) • Simulation parameters (low irradiance, temperature….) unclear, missing PAN files	• Module mishandling (glass breakage) • Module mishandling (cell breakage) • Module mishandling (defective backsheet) • Incorrect connection of modules • Bad wiring without fasteners	• Hotspot • Delamination • Glass breakage • Soiling • Shading • Snail tracks • Cell cracks • PID • Failure bypass diode and junction box • Corrosion in the junction box • Theft of modules • Module degradation • Slow reaction time for warranty claims, vague or inappropriate definition of procedure for warranty claims • Spare modules no longer available, costly string reconfiguration	• Undefined product recycling procedure

Risk Descriptions

Component	Module			
Defect	**Delamination**			
Brief description	Delamination resulting for the loss of adhesion and they are bright, milky areas that stand out in colour from the remaining cells.			
Detailed description	The adhesion between the glass, encapsulant, active layers, and back layers can be compromised for many reasons.Delamination is more frequent and severe in hot and humid climates. Typically, if the adhesion is compromised because of contamination (e.g. improper cleaning of the glass) or environmental factors, delamination will occur, followed by moisture ingress and corrosion. Delamination at interfaces within the optical path will result in optical reflection and subsequent loss of current power from the modules. Delamination on cells led to decrease in Isc			
References	Review of Failures of Photovoltaic Modules, IEA - International Energy Agency. Study of Delamination in acceleration tested PV modules – Neelkanth G., Mandar B.			
Normative References	IEC 61215	IEC 61730	IEC 61446	
Causes	Installation: Mishandling	Product defects: Material defect	Maintenance: Environmental influence & Degradation	
Detection	Visual inspection			
CPN [€/kWp]	Time to detect in [h]	Time to repair/substitution [h]	Repair/substitution time [h]	Power loss [%]
				1
	Rm (average cost of detection/component) [€]	Rsu (average substitution cost/component) [€]	Rr (average repair cost/component) [€]	Rp (average transport costs per component) [€]
	0	108	0	10
Action	Modules with large delamination must be replaced.			

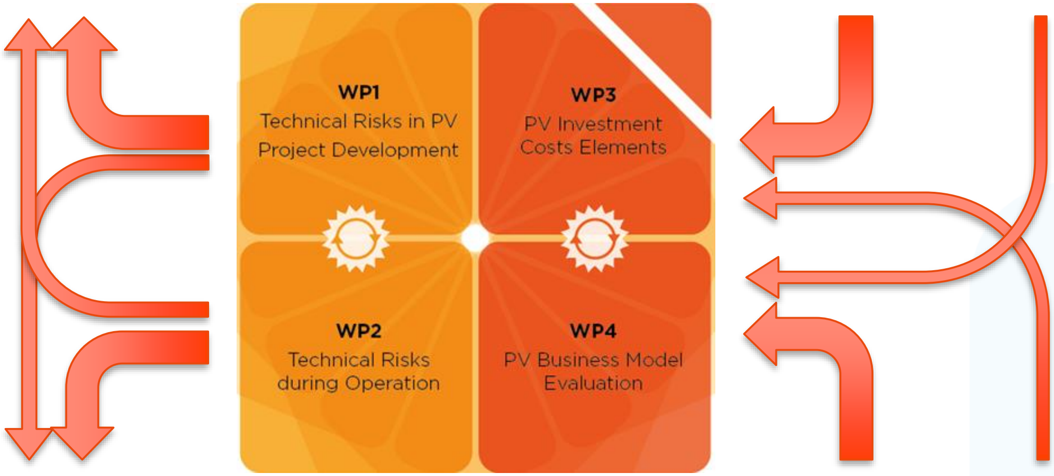
		
Delamination of a module	Delamination	Browning and delamination of a module

Component	**Inverter**			
Defect	**Overheating**			
Brief description	During temperature derating, the inverter reduces its power to protect components from overheating.			
Detailed description	Temperature derating protects sensitive inverter components from overheating. When the monitored components reach the maximum operating temperature, the device shifts it operating point to a lower power. During this process, power is reduced step-by-step. In the extreme case, the inverter switches off completely. As soon as the temperature of the threatened components falls below the critical value, the inverter returns to the optimal operating point. Temperature derating can occur for various reasons, e.g. when installation conditions interfere with the inverter's heat dissipation.			
References	UEN103910			
Normative References	IEC 62116	DIN VDE 0126	EN50530	
Causes	Installation: Improper installation	Product defects: Fan failure	Maintenance: Fan or dust is blocking heat dissipation	
Detection	Visual Inspection, Inverter Monitoring, Datalogger			
CPN [€/kWp]	Time to detect in [h]	Time to repair/substitution [h]	Repair/substitution time [h]	Power loss [%]
				20
	Rm (average cost of detection/component) [€]	Rsu (average substitution cost/component) [€]	Rr (average repair cost/component) [€]	Rp (average transport costs per component) [€]
	0	0	377	10
Action	The filters and in general heat dissipation path should be clear.			

		
Soilled air filter	Soilled air filter	Ventilation failure

Cost Priority Number and Uncertainty

Risks to which we can assign an **uncertainty** (e.g. irradiance, degradation)
Variance and uncertainty → Link to financial probability parameters



Risks to which we can assign a **CPN** (e.g. module and inverter failure)
Failure collection and CPN table → CPN value is an indication of preventive and corrective O&M (Euros/kWp/year)

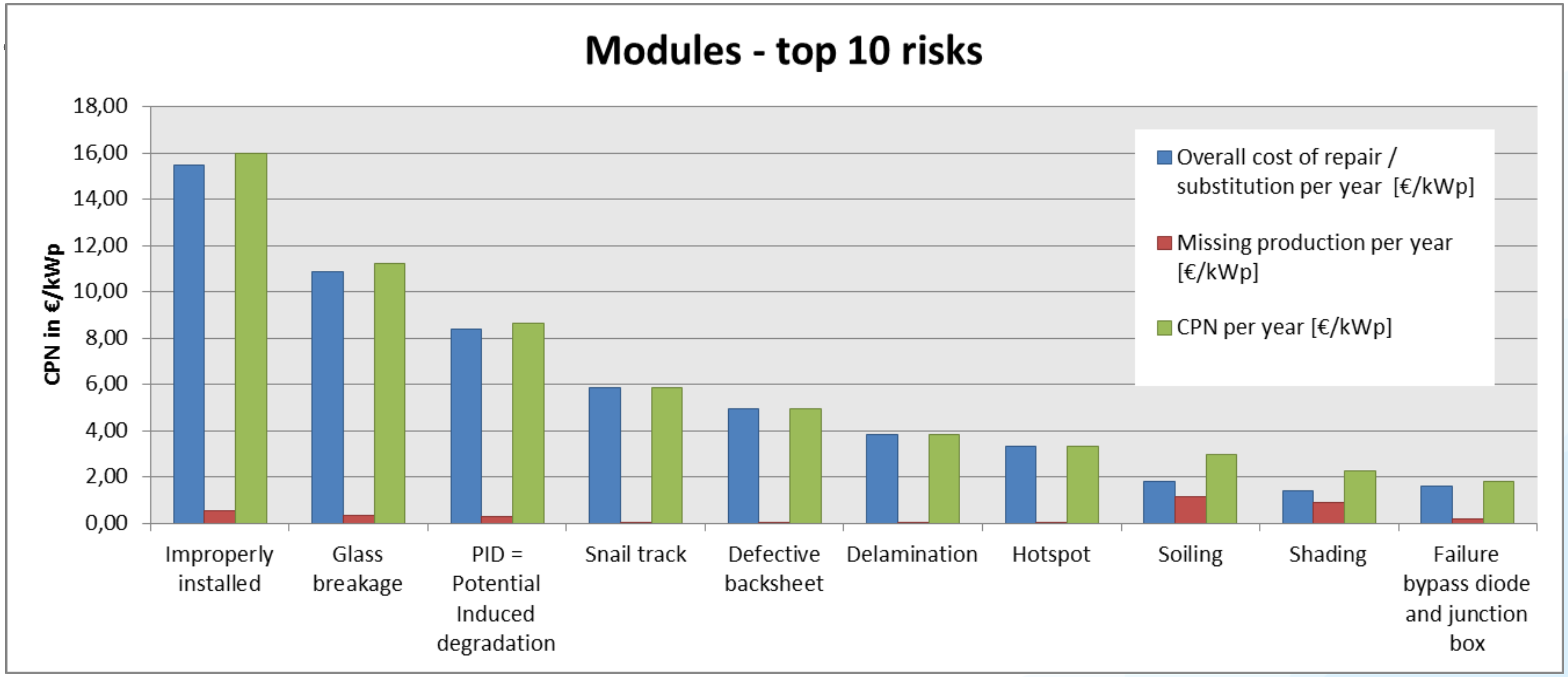
Technical Risk Data Base (442 MWp)

	Total number of plants	Total Power [kWp]	Average number of years
TOTAL	772	441676	2.7
Components	**No. tickets**	**No. Cases**	**No. Components**
Modules	473	678801	2058721
Inverters	476	2548	11967
Mounting structures	420	15809	43057
Connection & Distribution boxes	221	12343	20372
Cabling	614	367724	238546
Transformer station & MV/HV	53	220	558
Total	2257	1077445	2373222

$$CPN = C_{down} + C_{fix}$$

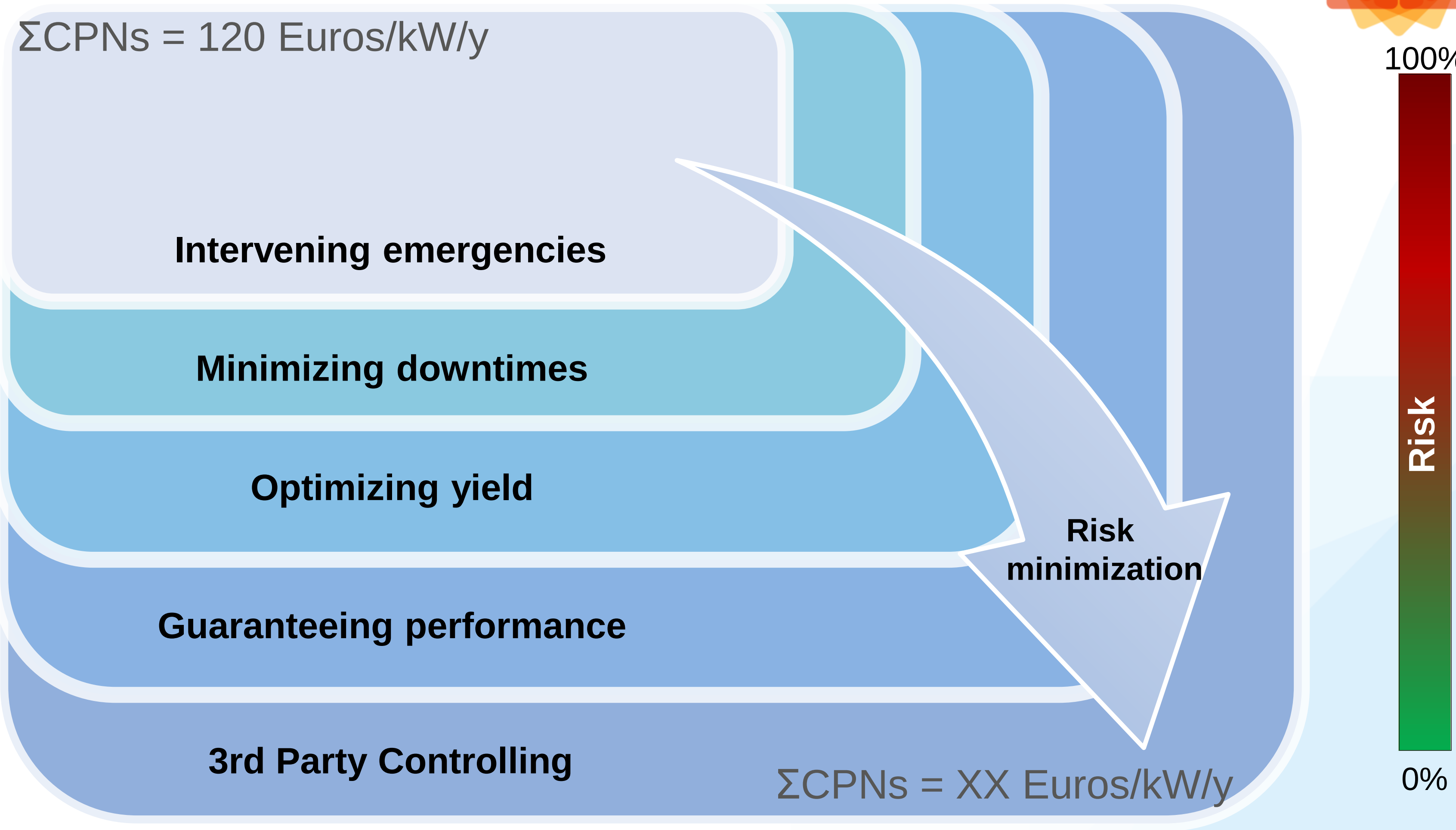
CPN is given in Euros/kW/year
It gives an indication of the economic impact of a failure due to downtime and investment cost

Top 10 Module CPNs



- Highest risk consists of a group of installation failures (mishandling, connection failures, missing fixation, etc.)
- Variety of failures detected by different techniques (VI, IR, EL, IV-Curves)

CPN Evaluation of Mitigation Measures



Risk Mitigation Measures

- **Preventive measures**
  - Component testing
  - Design review and construction monitoring
  - Qualification of EPC

- **Corrective measures**
  - Advanced monitoring system
  - Basic monitoring system
  - Advanced inspection
  - Visual inspection
  - Spare part management

Mitigation Measures

Risk mitigation fact sheet

Name	Component Testing – PV modules	Preventive	X
		Corrective	X
Short description			
High-quality photovoltaic modules are subject to a number of requirements. First, they have to deliver the guaranteed rated power reliably, while withstanding an extremely wide range of environmental conditions. They must also be safe and durable, ensuring the system high yield over the long- term period. However, with testing actions the quality of the modules can be fully certified.			

Actions	Short description	Uncertainty	Cost
PID Testing	PID refers to potential induced performance degradation in crystalline silicon photovoltaic modules. It occurs when the module voltage potential and leakage current cause ion mobility within the module. The degradation accelerates with exposure to humidity, temperature and voltage potential. PID tests simulate the practical conditions in the PV system, and verify the module performance and power output under high voltage.		0.5 – 1 €/kW
Insulation measurement	A typical module would have a structure of glass–EVA–cell–EVA–tedlar back sheet. Apparent physical deteriorations of modules under long-term field-exposure have been observed. This measurement ensures the quality of the materials in order to ensure the insulation of the module.		0.2 – 0.7 €/kW
STC Power Measurements	Measurements under standard test conditions for determining IV and electrical output. Measurement conditions (STC): 1000 W/m², AM 1.5, 25°C.		0.3 – 0.8 €/kW
EL Imaging	Electroluminescence (EL) imaging is a quality assessment tool for both crystalline silicon and thin film solar modules. It is able of accurately detecting numerous failures and ageing effects e.g. cracks and breakages, in some cases defective edge insulation, shunts etc.		0.5 – 1 €/kW
IR inspection	The infrared imaging (IR) inspection of photovoltaic systems allows the detection of potential defects at the cell and module level as well as the detection of possible electrical interconnection problems. The inspections are carried out under normal operating conditions and do not require a system shut down.		0.5 – 1 €/kW

Risk mitigation flash card

Risk	*1. Insufficient EPC technical specifications to ensure that selected components are suitable for use in the specific PV plant environment of application*	*Phase of risk occurrence*	
		Procurement ✓	*Planning*
		O&M	*Construction*

Key takeaway: *PV plant component specification and requirement in the EPC contract should be as detail as possible to ensure that the components procured are suited for the intended PV installation specific application, site and environment*

Impact of risk	LCOE variables impacted by this risk:	CAPEX	OPEX	Yield
				✓

Mitigations

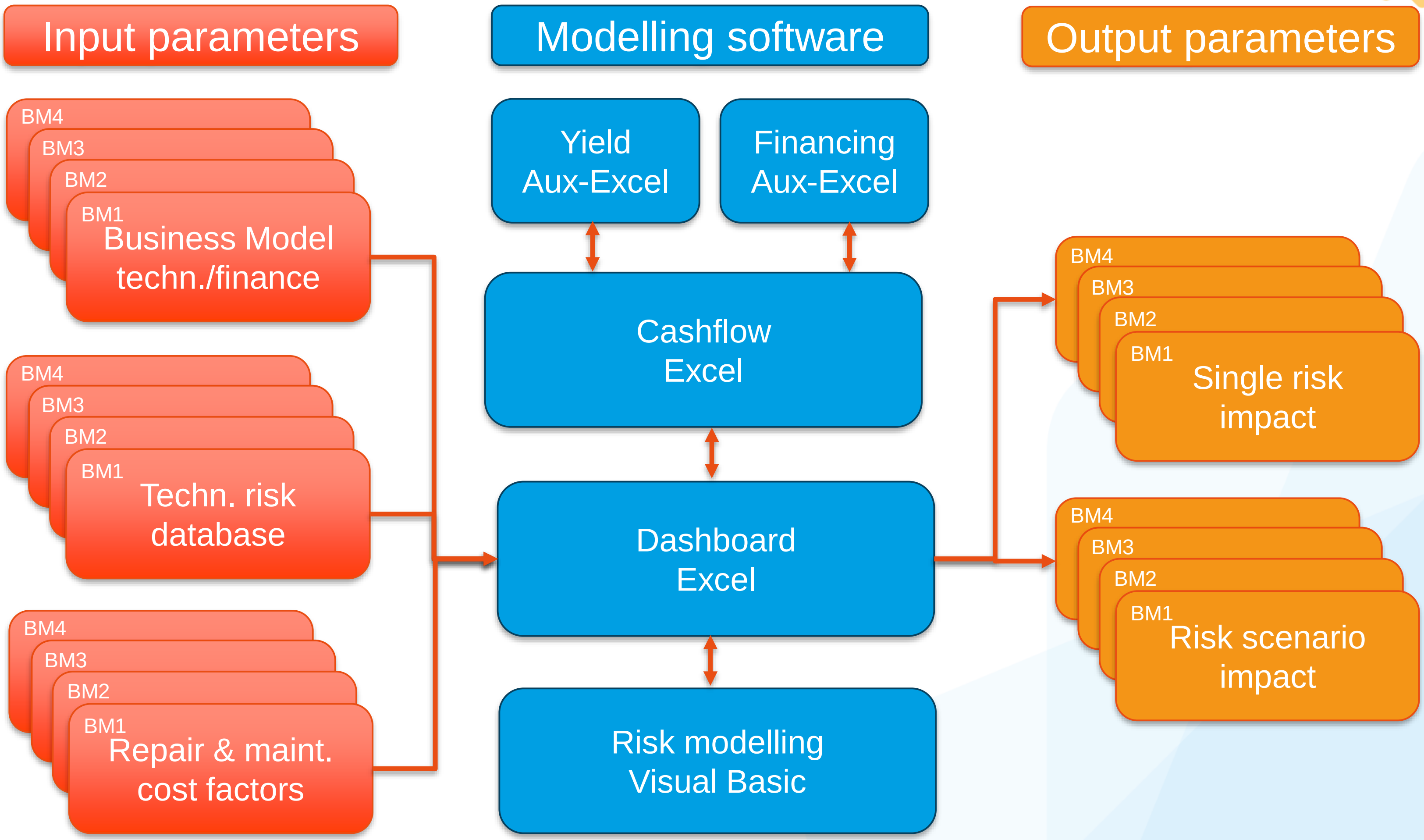
- ☐ Component testing
- ■ Design review + construction monitoring
- ☐ EPC qualification
- ☐ Advanced monitoring
- ☐ Basic monitoring
- ☐ Advanced inspection
- ☐ Visual inspection
- ☐ Yield/performance test

When specifying the technical requirements for PV plant components in the EPC contract, in addition to the component type and quantity, the specifications should also include:

- All applicable certifications and conformances (e.g. IEC61215, IEC61730, IEC61701, IEC62804, IEC61716 for modules; IEC62109, IEC61000 for inverters; CE mark of compliance for all electrical components)
- The environmental condition the components will be installed in (temperature, humidity, wind and snow load, any special chemical exposure, corrosion risk etc.)
- For PV modules, module component bill of materials and the proof of IEC certification documents for these materials

Impact of mitigation	LCOE variables impacted by the risk mitigations:	CAPEX	OPEX	Yield
				✓

Financial Modelling Tool

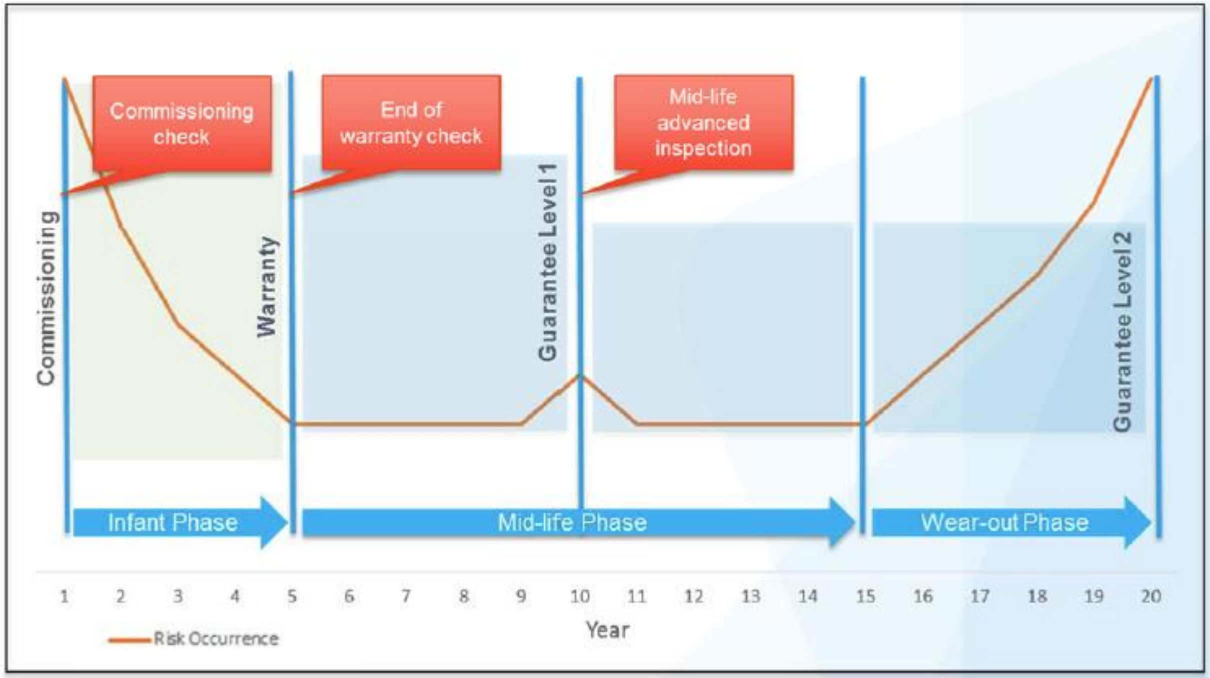


Business models under Evaluation

	Description
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)
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)

The cash flow modelling for all business models on a 100% equity financing structure. Thus the economic impact of technical risks remains more objective and comparable and is not influenced by different financial leverage ratios which are subject to the individual risk/return preferences of individual investors

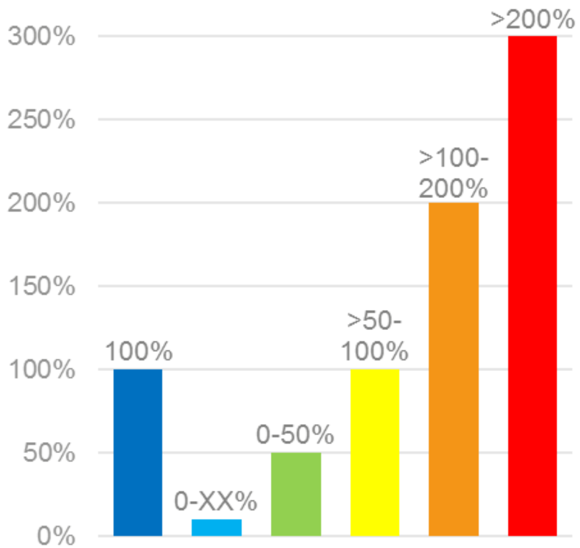
Risk mitigation plan for the BMs



- A PV project will be exposed to several technical risks throughout its operational phase
- For each of the BM, a technical risk scenario has been created – combination of 4 technical risks from each project phase
- Repair and Maintenance cost assumptions have been made based on a list of >3500 insurance claims from all EU

*The impact of technical risks can differ to a large extend between **the base case** and **the worst case**. The base case of the cash flow model contains a provision for regular operations and maintenance costs. The worst case can exceed these provision and might require the injection of additional equity capital, in case the risk impact is neither covered by warranties, guarantees or insurances*

Impact Categories of Technical Failures



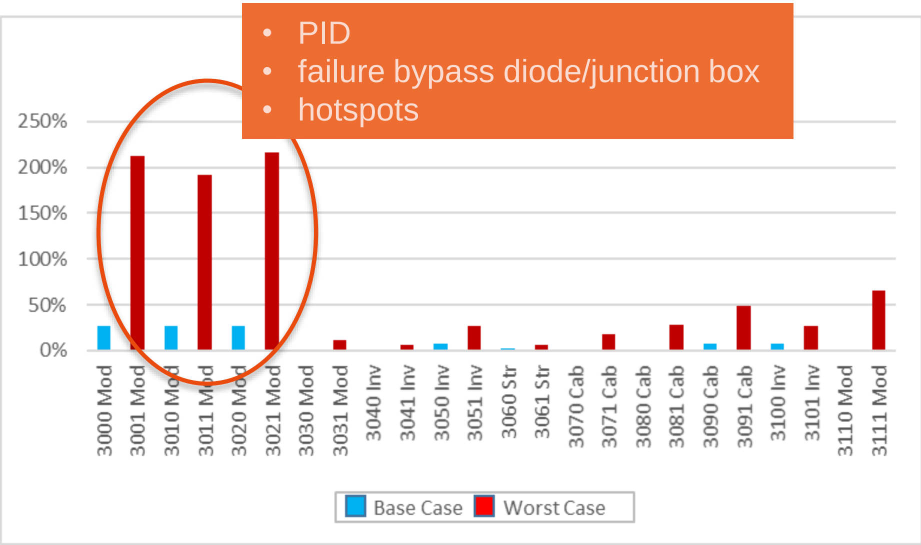
- **Reference base (100%):** 12 months revenues from first calender year of full operations
- **Failure category 0 - (0-xx%):** Regular operations and maintenance provisions
- **Failure category 1- (0-50%):** Covered by 6 months reserve accounts
- **Failure category 2 - (>50-100%):** Covered by 12 months 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

A reserve account is often included in the cash flow model to buffer unanticipated business model risks. The size of the reserve account varies with the individual stability requirements of the investor or the financing bank. The size of the reserve account is measured as a fraction of the 12 months revenues in the first year of PV system operations - DSRA.

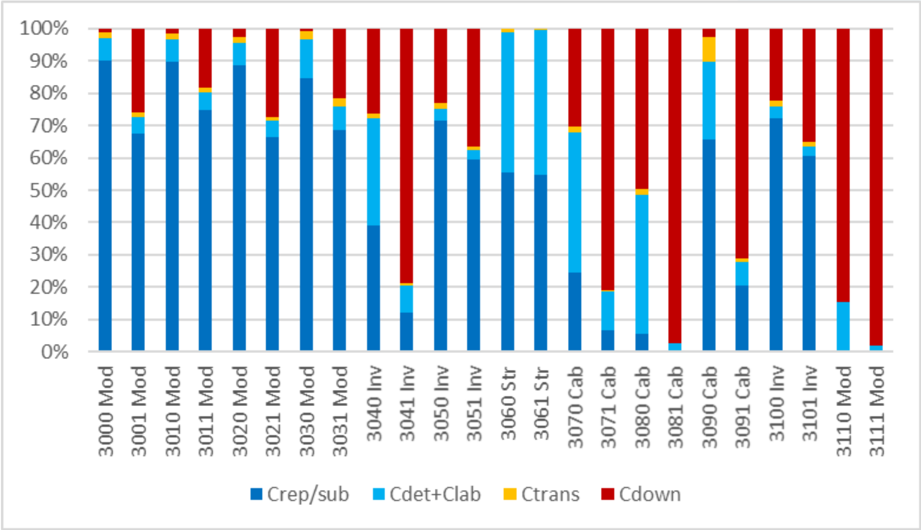
Risk Modelling Results for single technical risks (BM3)

Business model 3 represents a utility scale PV system with a nominal capacity of 7.6 MWp located in central UK. The system consists of 7 central inverters, 190 strings per inverter and 22 crystalline silicon modules per string. The system was commissioned in January 2011. The owner is a financial investor interested in maximum system profitability

Results by failure category

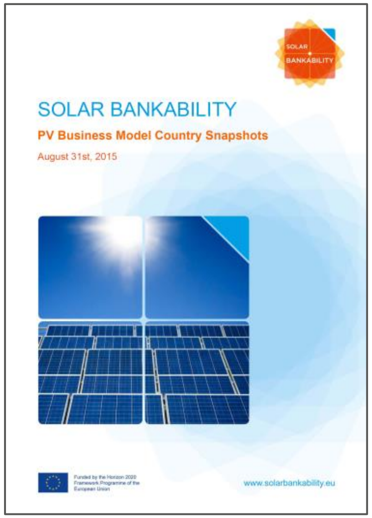


Results by cost category

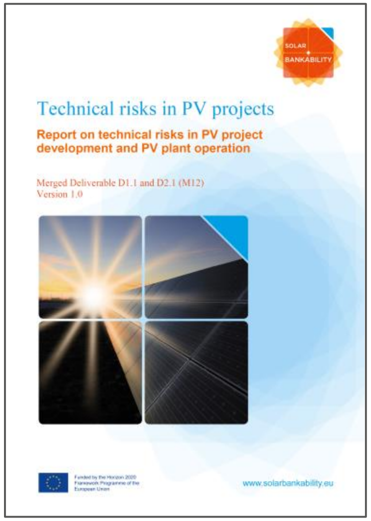


Solar Bankability Project Reports

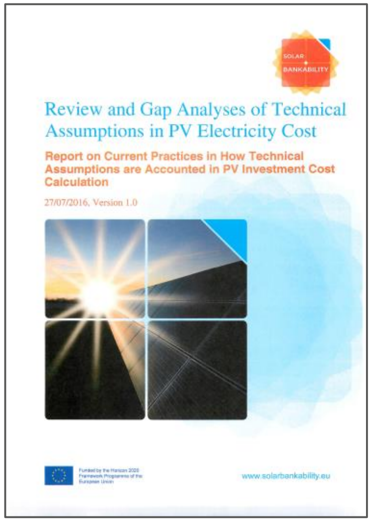
PV business models


SOLAR BANKABILITY
PV Business Model Country Snapshots
August 31st, 2015
www.solarbankability.eu

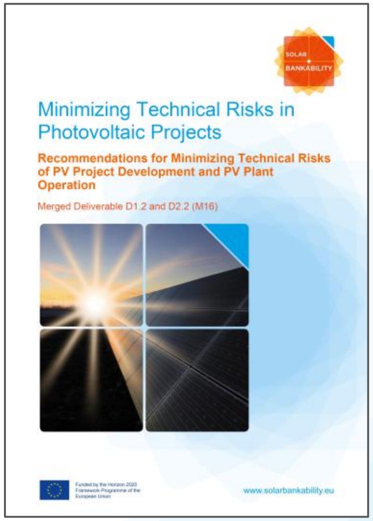
Technical risks


Technical risks in PV projects
Report on technical risks in PV project development and PV plant operation
Merged Deliverable D1.1 and D2.1 (M12)
Version 1.0
www.solarbankability.eu

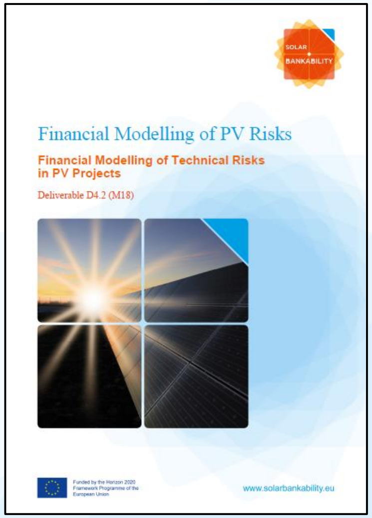
Gap analysis


Review and Gap Analyses of Technical Assumptions in PV Electricity Cost
Report on Current Practices in How Technical Assumptions are Accounted in PV Investment Cost Calculation
27/07/2016, Version 1.0
www.solarbankability.eu

Mitigation measures


Minimizing Technical Risks in Photovoltaic Projects
Recommendations for Minimizing Technical Risks of PV Project Development and PV Plant Operation
Merged Deliverable D1.2 and D2.2 (M16)
www.solarbankability.eu

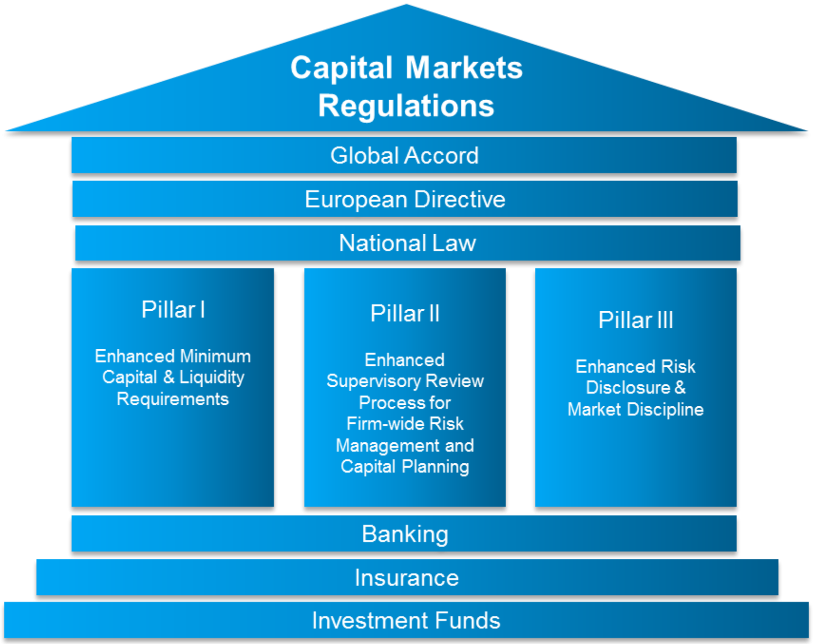
Financial modelling


Financial Modelling of PV Risks
Financial Modelling of Technical Risks in PV Projects
Deliverable D4.2 (M18)
www.solarbankability.eu

Free download of reports from project website: www.solarbankability.eu

Basel III and Solvency II

New capital market regulations require a thorough due diligence and ongoing risk management procedures. Banks and insurances are requested to either implement a qualified in-house risk rating or to take advantage of external professional rating services.



The Solar Bankability project enhances

risk disclosure and management procedures

Thank you

PRESENTED BY

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This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 649997.
The content of this report reflects only the author's view and the Commission is not responsible for any use that may be made of the information it contains

Funded by the Horizon 2020
Framework Programme of the
European Union

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