Solar Bankability Webinar
20 October 2016

Technical Risks and Mitigation Measures in PV Project Development and during Operation

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Ulrike Jahn, TÜV Rheinland Energy
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.

www.solarbankability.eu
Technical Risks Matrix

Product Development

- Product testing
- Planning
- Transportation / installation
- O&M
- Decommissioning

Assessment of PV Plants

- Modules
- Soiling
- Shadow diagram
- Modules mismatch
- Module mishandling (glass breakage)
- Module mishandling (cell breakage)
- Module mishandling (defective backsheets)
- Incorrect connection of modules
- 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

- 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
- Module mishandling (glass breakage)
- Module mishandling (cell breakage)
- Module mishandling (defective backsheets)
- Incorrect connection of modules
- Bad wiring without fasteners
- Soiling
- 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
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-Undefined product recycling procedure
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

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<tr>
<td>Rm (average cost of detection/component) [€]</td>
<td>Rsu (average substitution cost/component) [€]</td>
<td>Rp (average transport costs per component) [€]</td>
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</table>

Action: The filters and in general heat dissipation path should be clear.

Delamination of a module

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

Normative References: IEC 61215, IEC 61730, IEC 61446

Causes:
- Installation: Mishandling
- Product defects: Material defect
- Maintenance: Environmental influence & Degradation

Detection: Visual inspection

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<td>Rsu (average substitution cost/component) [€]</td>
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Action: Modules with large delamination must be replaced.

Delamination of a module

Soiled air filter

Ventilation failure
## Technical Risks Matrix

<table>
<thead>
<tr>
<th>Product Development</th>
<th>Assessment of PV Plants</th>
</tr>
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<tbody>
<tr>
<td><strong>Product testing</strong></td>
<td></td>
</tr>
<tr>
<td><strong>List of failures</strong></td>
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<tr>
<td>Modules</td>
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<td>Inverter</td>
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<td>Mounting structure</td>
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<td>Connection &amp;</td>
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<td>distribution boxes</td>
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<td>Cabling</td>
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<td>Potential equalization</td>
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<td>Weather station,</td>
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### Product Development
- 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

### Assessment of PV Plants

### Uncertainty
### Technical Risks Matrix

<table>
<thead>
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<th>Product Development</th>
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<tr>
<td><strong>Planning</strong></td>
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<table>
<thead>
<tr>
<th>Category</th>
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<tbody>
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- **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**
Technical Risks Matrix

Product Development

Assessment of PV Plants

Planning

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Uncertainty
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### Planning

- Solar Bankability Webinar
- 10/20/2016
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### Precursors
- Module mishandling (glass breakage)
- Module mishandling (cell breakage)
- Module mishandling (defective backsheet)
- Incorrect connection of modules
- Bad wiring without fasteners
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### List of failures

- Hotspot
- Delamination
- Glass breakage
- Soiling
- Shading
- Snail tracks
- Cell cracks
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- 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

### Quantifiable impact

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10/20/201
## Technical Risk Matrix

### List of failures

- Hotspot
- Delamination
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### Indirect impact
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Classification of technical risks

Risk Matrix

Product Development
- Product testing
- Planning
- Transportation / installation

Assessment of PV Plants
- O&M
- Decommissioning

Year 0 risks
- Uncertainty
- Precursors
- Quantifiable impact
- Indirect impact

Impact
- on uncertainty (exceedance P)
- on CAPEX
- on CPN (O&M)
Quantification of economic impact of technical risks

- 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)
Procedure for the calculation of CPNs

Risks to which we can assign a CPN (e.g. module and inverter failure during O&M)

a) Economic impact due to downtime and/or power loss (kWh to Euros)

- Failures might cause downtime or % in power loss
- Time is from failure to repair/substitution and should include: time to detection, response time, repair/substitution time
- Failures at component level might affect other components (e.g. module failure might bring down the whole string)

b) Economic impact due to repair/substitution costs (Euros)

- Cost of detection to account for various techniques (IR for hotspots, EL for crack cells, Visual inspection, monitoring systems, etc)
- Cost of transportation of component
- Cost of labour (linked to downtime)
- Cost of repair/substitution
Procedure for the calculation of CPNs

Risks to which we can assign a CPN (e.g. module and inverter failure during O&M)

1. calculation of average downtime for a specific failure [h/specific failure]

\[ t_{down,fail} = (t_{td} + \frac{t_{tr}}{t_{ts}}) \times PL \times M + t_{fix} \times M \]

PL = Power loss in %
M = Multiplier to take into account impact at higher component level
Procedure for the calculation of CPNs

Risks to which we can assign a CPN (e.g. module and inverter failure during O&M)

2. Calculation of total downtime for the n number of components failures over a certain period [h/period]
   \[ t_{down} = t_{down,fail} \times n_{fail} \]

3. Calculation of total downtime normalised by components [h/period/components]
   \[ t_{down,comp} = t_{down} / n_{comp} \]

4. Calculation of occurrence over a time \( t_{ref} \) [fraction or % of components]
   \[ O = t_{down,comp} / t_{ref} \]
   \( t_{ref} \) could be either the equivalent hours (specific yield), the total number of hours per year or the number of sun hours. Occurrence can thus be considered as the energy loss in % caused by a specific failure over a certain period.
Procedure for the calculation of CPNs

Risks to which we can assign a CPN (e.g. module and inverter failure during O&M)

5. calculation of production losses, L, due to downtime [kWh]
   \[ L = O \times S \]
   The severity, S, is calculated as the total plant(s) production over one year [kWh/period components]

6. calculation of downtime costs as missing production/savings in Euros/period or Euros/kWp/period
   \[ C_{\text{down}} = L \times (\text{FIT} + \text{PPA} + \text{RCE}) \]
   For the calculation of the costs due to downtime, it is important to consider the missing income of feed in tariffs, the missing income from PPA, and/or the missing savings generated by PV plants installed on roofs/facades. RCE: Retail Cost of Electricity

Methodology allows for geographical analysis and differentiation for PV plant typology and market segment
Procedure for the calculation of CPNs

Risks to which we can assign a CPN (e.g. module and inverter failure during O&M)

Methodology allows for the inclusion of the cost of detection

\[ C_{\text{fix}} = (C_{\text{det}} + C_{\text{rep/sub}} + C_{\text{transp}}) \times n_{\text{fail}} + C_{\text{lab}} \times t_{\text{fix}} \times n_{\text{fail}} \]

7. The costs related to fixing the failure results from the sum of the costs of repair/substitution, costs of detection, costs of transport and cost of labour

8. The calculation of the Cost Priority Number is then given by \( \text{CPN} = C_{\text{down}} + C_{\text{fix}} \)
Technical Risks collection

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

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

Tickets from O&M operators as corrective or periodic maintenance in paper or electronic form

Visual and detailed inspection
Inverters

Identification of Technical Risks from monitoring

- First results based on inverter replacements since 2010Q1 (population: 41,000 inverters)
- Data from monitored plants

[Graph showing cumulative share of inverters replaced over different quarters and years with various colors indicating different time periods after installation.]
Inverters

Identification of Technical Risks from monitoring

- Replacement rate - initial phase of ‘bathtub curve’
CPN is given in Euros/kW/year
It gives an indication of the economic impact of a failure due to downtime and investment cost

\[ \text{CPN} = C_{\text{down}} + C_{\text{fix}} \]

<table>
<thead>
<tr>
<th>Components</th>
<th>Total number of plants</th>
<th>Total Power [kWp]</th>
<th>Average number of years</th>
</tr>
</thead>
<tbody>
<tr>
<td>TOTAL</td>
<td>TOTAL</td>
<td>772</td>
<td>441676</td>
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<tr>
<td>Components</td>
<td>No. tickets</td>
<td>No. Cases</td>
<td>No. Components</td>
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<td>Modules</td>
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<td>2058721</td>
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<tr>
<td>Inverters</td>
<td>476</td>
<td>2548</td>
<td>11967</td>
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<td>Mounting structures</td>
<td>420</td>
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<tr>
<td>Connection &amp; Distribution boxes</td>
<td>221</td>
<td>12343</td>
<td>20372</td>
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<tr>
<td>Cabling</td>
<td>614</td>
<td>367724</td>
<td>238546</td>
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<tr>
<td>Transformer station &amp; MV/HV</td>
<td>53</td>
<td>220</td>
<td>558</td>
</tr>
<tr>
<td>Total</td>
<td>2257</td>
<td>1077445</td>
<td>2373222</td>
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</table>

- Do all failures have a relevant economic impact?
- Are data biased? Location / Technology / Monitoring system

**Biased** – site was surveyed due to a reported problem
**Unbiased** – site was surveyed as part of routine maintenance
**Extrapolated** – Only a part of the plant was surveyed and data extrapolated
Definition of scenarios

- **Never detected (CPN\textsubscript{ndet})**
  Failure is undetected. **Losses due to downtime** over a time \( t_{td} \)

- **Failure fix (CPN\textsubscript{failfix})**
  Failure is detected. 1 Month of lead time to repair/substitution

- Failures are equally distributed over time
- No increase in Performance Losses over time
- Yield is considered as an average at national level (not site specific)
- The real scenario would be a combination of the two
CPN Results - Components and Market Segments

- PV modules - Utility scale

- 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)
### Technical Risks collection: occurrence and CPN

<table>
<thead>
<tr>
<th></th>
<th>no. cases</th>
<th>no. components</th>
<th>Years</th>
<th>Occurrence</th>
<th>Occurrence/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modules</td>
<td>678,640</td>
<td>2,058,721</td>
<td>2.68</td>
<td>33%</td>
<td>12%</td>
</tr>
<tr>
<td>Inverters</td>
<td>2,474</td>
<td>11,967</td>
<td>2.68</td>
<td>21%</td>
<td>8%</td>
</tr>
</tbody>
</table>

#### Module Failure share

- **Soiling**: 23.4%
- **Shading**: 16.8%
- **EVA discoloration**: 11.6%
- **Glass breakage**: 6.5%
- **PID**: 5.0%

#### Inverter Failure share

- **Fan failure and overheating**: 21.8%
- **Fault due to grounding issues**: 4.9%
- **Inverter firmware issue**: 3.8%
- **Burned supply cable and/or socket**: 2.2%
- **Polluted air filter**: 3.3%
- **Inverter pollution**: 1.5%

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**CPN failure fix**

- **Soiling**: €10.00
- **Shading**: €8.00
- **EVA discoloration**: €6.00
- **Glass breakage**: €4.00
- **Cell cracks**: €2.00
- **PID = Potential Induced degradation**: €
- **Snail track**: €
- **Defective backsheet**: €
- **Hotspot**: €
- **Delamination**: €
- **Overheating junction box**: €
- **Failure bypass diode and junction box**: €
- **Corrosion of cell connectors**: €
- **Corrosion in the junction box**: €
- **Theft of modules**: €
- **Module damaged due to fire**: €
CPN results - Components and market segments

- PV modules – All market segments

**Who bears the cost? Who bears the risk?**

~60 Euros/kW/y

- Defective backsheet
- Soiling
- Shading
- Delamination
- Glass breakage
- Hotspot
- Snail track
- Theft of modules
- PID = Potential Induced degradation
- Failure bypass diode and junction box

Downtime losses - base case [€/kWp/a]
Failure fix [€/kWp/a]
CPN results - Comparison studies

- Worst scenario vs base scenario for modules (higher PL)

\[ \Sigma CPN_{ndet} = \sim 11 \text{ Euros/kWp/y} \]

\[ \Sigma CPN_{ndet} = \sim 19 \text{ Euros/kWp/y} \]

- Solar Bankability Webinar
CPN results - Comparison studies

- Affected components vs total components: CPN ratio

Failures calculated over the whole database

Failures calculated over the affected plants
CPN results - Comparison studies

• Influenced components vs total components

Defined as CPN ratio

• High CPN ratio for product failures or non technical factors
Evaluation of Mitigation Measures

\[ \Sigma \text{CPNs} = 120 \text{ Euros/kW/y} \]

- Intervening emergencies
- Minimizing downtimes
- Optimizing yield
- Guaranteeing performance
- 3rd Party Controlling

\[ \Sigma \text{CPNs} = \text{XX Euros/kW/y} \]
Evaluation of Mitigation Measures
Component testing, design verification, construction monitoring
O & M, performance monitoring

CAPEX & OPEX depending on mitigation measures

Why bears the cost? Who bears the risk?

Risk minimization

∑CPNs = ~ 120 Euros/kW/y

∑CPNs = ~ XX Euros/kW/y

CAPEX & OPEX depending on mitigation measures
Description of Categories of 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
## Fact Sheets for Mitigation Measures

<table>
<thead>
<tr>
<th>Name</th>
<th>Short description</th>
<th>Uncertainty</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component Testing – PV modules</td>
<td>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.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Preventive</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corrective</td>
<td>X</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **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. Cost: 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. Cost: 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. Cost: 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. Cost: 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. Cost: 0.5 – 1 €/kW
Mitigation Measure Approach

\[ CPN_{new} = CPN_{mit} + Cost_{mit} \]

\( CPN_{mit} \) is the sum of the mitigated CPN costs

\( Cost_{mit} \) are the costs incurred for the mitigation measures.

\[ CPN_{mit} = C_{down,mit} + C_{fix,mit} \]

\[ C_{down,td,mit} = \alpha \cdot n_{fail}/n_{comp} \cdot \beta \cdot t_{td}/t_{ref} \cdot PL \cdot M \cdot PPA \cdot Y \]
\[ = \alpha \cdot \beta \cdot C_{down,td} \]

\[ C_{fix,mit} = \alpha \cdot n_{fail} \cdot [C_{det/mit} + C_{rep/sub} + C_{trans} + (C_{lab} \cdot t_{fix})] \]
\[ = \alpha \cdot C_{fix} \]
## Mitigation Measure Approach

List of 8 defined MMs, their mitigation factors and affected parameters

<table>
<thead>
<tr>
<th>Mitigation Measure</th>
<th>Risk Mitigation Factor</th>
<th>Affected Parameter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component testing – PV modules</td>
<td>α</td>
<td>number of failures</td>
</tr>
<tr>
<td>Design review + construction monitoring</td>
<td>α</td>
<td>number of failures</td>
</tr>
<tr>
<td>Qualification of EPC</td>
<td>α</td>
<td>number of failures</td>
</tr>
<tr>
<td>Advanced monitoring system</td>
<td>β</td>
<td>time to detection</td>
</tr>
<tr>
<td>Basic monitoring system</td>
<td>β</td>
<td>time to detection</td>
</tr>
<tr>
<td>Advanced inspection</td>
<td>β</td>
<td>time to detection</td>
</tr>
<tr>
<td>Visual inspection</td>
<td>β</td>
<td>time to detection</td>
</tr>
<tr>
<td>Spare part management</td>
<td>γ</td>
<td>time to repair/substitution</td>
</tr>
</tbody>
</table>
Mitigation Measure Approach

Definition of impact classes with respect to risk mitigation factor (RMF)

<table>
<thead>
<tr>
<th>Component</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modules</td>
<td>Snail track</td>
</tr>
<tr>
<td>Modules</td>
<td>Improperly installed</td>
</tr>
<tr>
<td>Modules</td>
<td>Glass breakage</td>
</tr>
<tr>
<td>Modules</td>
<td>Broken module</td>
</tr>
<tr>
<td>Modules</td>
<td>Theft of modules</td>
</tr>
<tr>
<td>Modules</td>
<td>Module damaged due to fire</td>
</tr>
<tr>
<td>Modules</td>
<td>Failure bypass diode and junction box</td>
</tr>
<tr>
<td>Modules</td>
<td>Shading</td>
</tr>
<tr>
<td>Modules</td>
<td>Soiling</td>
</tr>
<tr>
<td>Modules</td>
<td>Cell cracks</td>
</tr>
<tr>
<td>Modules</td>
<td>Doping</td>
</tr>
<tr>
<td>Equipment</td>
<td>Salt tracking</td>
</tr>
<tr>
<td>Equipment</td>
<td>Insulation, isulation and/or coating of steel</td>
</tr>
<tr>
<td>Equipment</td>
<td>Grounding</td>
</tr>
<tr>
<td>Equipment</td>
<td>Cables</td>
</tr>
<tr>
<td>Equipment</td>
<td>Failure bypass diode and</td>
</tr>
</tbody>
</table>
Mitigation Measure Approach

8 defined mitigation measures with medium, low and high cost scenarios

<table>
<thead>
<tr>
<th>Mitigation measure</th>
<th>Defined costs Scenario 1 (medium costs)</th>
<th>Defined costs Scenario 2 (low costs)</th>
<th>Defined costs Scenario 3 (high costs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component testing – PV modules</td>
<td>3 €/kWp (0.15 €/kWp/year)</td>
<td>1 €/kWp (0.05 €/kWp/year)</td>
<td>10 €/kWp (0.5 €/kWp/year)</td>
</tr>
<tr>
<td>Design review + construction monitoring</td>
<td>20 €/kWp (1 €/kWp/year)</td>
<td>10 €/kWp (0.5 €/kWp/year)</td>
<td>40 €/kWp (2 €/kWp/year)</td>
</tr>
<tr>
<td>Qualification of EPC</td>
<td>3 €/kWp (0.15 €/kWp/year)</td>
<td>1 €/kWp (0.05 €/kWp/year)</td>
<td>10 €/kWp (0.5 €/kWp/year)</td>
</tr>
<tr>
<td>Advanced monitoring system</td>
<td>2 €/kWp/year</td>
<td>1 €/kWp/year</td>
<td>3 €/kWp/year</td>
</tr>
<tr>
<td>Basic Monitoring system</td>
<td>0.5 €/kWp/year</td>
<td>0 €/kWp/year</td>
<td>1 €/kWp/year</td>
</tr>
<tr>
<td>Advanced Inspection</td>
<td>2 €/kWp/year</td>
<td>1 €/kWp/year</td>
<td>3 €/kWp/year</td>
</tr>
<tr>
<td>Visual Inspection</td>
<td>1 €/kWp/year</td>
<td>0.5 €/kWp/year</td>
<td>2 €/kWp/year</td>
</tr>
<tr>
<td>Spare part management</td>
<td>10 €/kWp (0.5 €/kWp/year)</td>
<td>2 €/kWp (0.1 €/kWp/year)</td>
<td>20 €/kWp (1 €/kWp/year)</td>
</tr>
</tbody>
</table>
Impact of Applied Mitigation Measures on and Ranking of CPN

Top 10 risks with and without mitigation measures in CPN
Impact of Applied Mitigation Measures

New CPN results of mitigation measure combinations for different FIX cost scenarios compared to CPN without mitigation measures.

![Graph showing CPN costs for different FIX scenarios](image)
Impact of Applied Mitigation Measures

Best combinations of mitigation measures for medium (1), low (2) and high (3) cost scenarios and their savings in CPN

<table>
<thead>
<tr>
<th>Rank</th>
<th>Component testing</th>
<th>Design review + construction monitoring</th>
<th>Qualification of EPC</th>
<th>Advanced monitoring system</th>
<th>Basic Monitoring system</th>
<th>Advanced Inspection</th>
<th>Visual Inspection</th>
<th>Spare part management</th>
<th>Saving [€/kWp]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
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<td>1</td>
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<td>1</td>
<td>1</td>
<td>1</td>
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<td>0</td>
<td>0</td>
<td>88.9</td>
</tr>
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<td>1</td>
<td>0</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>88.7</td>
</tr>
<tr>
<td>6</td>
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<td>1</td>
<td>0</td>
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<td>0</td>
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<td>88.6</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>88.5</td>
</tr>
<tr>
<td>8</td>
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<td>0</td>
<td>1</td>
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<td>1</td>
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<td>88.4</td>
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<tr>
<td>9</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
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<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>88.2</td>
</tr>
</tbody>
</table>

- **Scenario 1**

- **Scenario 2**

- **Scenario 3**
Impact of Applied Mitigation Measures

New CPN results of mitigation measure combinations of different LOSS scenarios based on high PPA compared to CPN without MM.
Impact of Applied Mitigation Measures

New CPN results of mitigation measure combinations of different LOSS scenarios based on low PPA compared to CPN without MM
Results of Deliverables on Mitigation Measures

For all 256 combinations of MM the CPN\textsubscript{new} for **FIX low cost scenario 2** shows better results than for FIX medium 1 and for FIX high cost scenarios 3.

**Preventive measures have the highest impact** on CPN\textsubscript{new} e.g. Qualification of EPC, will bring down CPN\textsubscript{new} to 75 €/kWp/year. E.g. Design review will further reduce CPN\textsubscript{new} to 40 €/kWp/year Simulation of failures for one scenario and economic impact (→ WP4).

Reducing the number of failures has the highest impact **due to the high substitution costs**.

The highest savings for all three cost scenarios can be achieved by applying the three preventive measures (component testing plus design review plus qualification of EPC). The savings may reach 90 €/kWp/year for the best combinations of selected mitigation measures.

For 99% of all mitigation measure combinations the scenarios will result in **economic benefit** by reducing the CPN\textsubscript{new} to values lower than 104.75€/kWp/year.
Results of Deliverables on Mitigation Measures

• Most of the scenarios are **economical beneficial** (lower than 13.5 € / kWp/year).

• Low cost **LOSS scenario 2** shows clear advantage, but the level of impact on the new CPN depends on the combination of selected mitigation measures.

• The highest savings for LOSS cost scenarios 1 and 2 can be achieved by applying the **three preventive measures** (component testing plus design review plus qualification of EPC). The savings may reach 10 €/kWp/year for the best combinations of selected mitigation measures.

• With low PPA it is more difficult to apply mitigation measures, which are economic beneficial.
Risk Reduction Example before Detection

**Input Data for Risk Reduction Example (PID)**

<table>
<thead>
<tr>
<th>Risk</th>
<th>Failure Rate plants</th>
<th>Failure Rate components</th>
<th>Initial Power Loss</th>
<th>Power Degradation rate</th>
<th>Occurrence degradation rate</th>
<th>PPA</th>
</tr>
</thead>
<tbody>
<tr>
<td>PID</td>
<td>10%</td>
<td>20%</td>
<td>20%</td>
<td>5%</td>
<td>5%</td>
<td>0.10€/kWh</td>
</tr>
</tbody>
</table>

**LOSS Scenario - PID**

<table>
<thead>
<tr>
<th>Year</th>
<th>CPN in €/kWp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 0</td>
<td>0.6</td>
</tr>
<tr>
<td>Year 1</td>
<td>1.35</td>
</tr>
<tr>
<td>Year 2</td>
<td>7.35</td>
</tr>
<tr>
<td>Year 3</td>
<td>1.35</td>
</tr>
<tr>
<td>Year 4</td>
<td>7.35</td>
</tr>
<tr>
<td>Year 5</td>
<td>6.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk</th>
<th>Mitigation</th>
<th>Mitigation cost (year 0)</th>
<th>Risk after 5 years</th>
<th>Reduced risk after 5 years</th>
<th>Savings after 5 years</th>
</tr>
</thead>
<tbody>
<tr>
<td>PID</td>
<td>PID Test</td>
<td>0.6 €/kWp</td>
<td>7.35 €/kWp</td>
<td>1.35 €/kWp</td>
<td>6.00 €/kWp</td>
</tr>
</tbody>
</table>
To be concluded

1. Technical risks were identified and categorised for components and phases of the value chain of a PV project.

2. The technical risks were broadly divided into risks to which one can assign an uncertainty to the initial yield assessment and risks to which one can assign a Cost Priority Number (CPN).

3. The overall methodology was created to allow the estimation of the economic impact of failures on the levelized cost of electricity (LCOE) and on business models of PV projects.

4. Mitigation measures have been identified along the value chain and assigned to various technical risks.

5. In this project we have aimed to evaluate the effectiveness of mitigation measures into the framework for the assessment of the economic impact of technical risk.
Final Public Workshop 7th-8th February 2017
Brussels, Belgium

Enhancement of PV Investment Attractiveness

Concept:
Target groups: Finance sector, insurance, EPCs, service providers, decision makers / broader attendance
1.5-day-Workshop including networking dinner
Fully paid workshop for max. 120 participants
Registration available: End of Oct 2016

Save the date: 7-8 Feb 2017!
Thank you!

- David Moser (Eurac),
- Ulrike Jahn (TÜV Rheinland Energy)

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