



# Technical Bankability Guidelines

## Recommendations to Enhance Technical Quality of existing and new PV Investments

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# Foreword

The photovoltaic (PV) sector has globally experienced a significant growth in the last decade, reflecting the recognition of PV as a clean and sustainable source of energy. Project investment has been and still is a primary financial factor in enabling sustainable growth in PV installations. When assessing the investment-worthiness of a PV project, different financial stakeholders such as investors, lenders and insurers will evaluate the impact and probability of investment risks differently depending on their investment goals. Similarly, risk mitigation measures implemented are subject to the investment perspective. In the financing process, the stakeholders are to elect the business model to apply and be faced with the task of taking appropriate assumptions relevant to, among others, the technical aspects of a PV project for the selected business model.

**The Solar Bankability project aims at establishing a common practice for professional risk assessment serving to reduce the risks associated with investments in PV projects.**

The risks assessment and mitigation guidelines are developed based on market data from historical due diligences, operation and maintenance records, and damage and claim reports. Different relevant stakeholders in the PV industries such as financial market actors, valuation and standardisation entities, building and PV plant owners, component manufacturers, energy prosumers and policy makers are engaged to provide inputs to the project.

The technical risks at the different phases of the project life cycle are compiled and quantified based on data from existing expert reports and empirical data available at the PV project development and operational phases. The Solar Bankability consortium performs empirical and statistical analyses of failures to determine the manageability (detection and control), severity, and the probability of occurrence. The impact of these failures on PV system performance and energy production are evaluated. The project then looks at the practices of PV investment financial models and the corresponding risk assessment at present days. How technical assumptions are accounted in various PV cost elements (capital expenditures (CAPEX), operational expenditures (OPEX), yield, and performance ratio) is inventoried. Business models existing in key countries in the EU market are gathered. Several carefully selected business cases are then simulated by performing technical risks and sensitivity analyses.

The results from the financial approach benchmarking and technical risk quantification are used to identify the gaps between the present PV investment practices and the available extensive scientific data in order to establish a link between the two. The findings are presented as best practice guidelines on how to translate important technical risks into different PV investment cost elements and business models. This will build a solid fundamental understanding among the different stakeholders and enhance the confidence for a profitable investment in PV projects.

The Solar Bankability project is funded by the Horizon 2020 Framework Programme of the European Commission. The project runs for two years from March 2015 to February 2017.

The Solar Bankability consortium is pleased to present this report as one of the public deliverables from the project work.

## Principal Authors

Matthias von Armansperg (ACCELIOS Solar GmbH)

Daniel Oechslin (ACCELIOS Solar GmbH)

Martina Schweneke (ACCELIOS Solar GmbH)

## Contributors

Caroline Tjengdrawira (3E, N.V.)

Mauricio Richter (3E, N.V.)

Jörg Mayer (German Solar Association, BSW)

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# Abbreviations

CAPEX	Capital expenditures
CPN	Cost priority number
EPC	Engineering, procurement and constructions
IR	Infrared imaging
EL	Electroluminescence imaging
O&M	Operation and maintenance
OPEX	Operational expenditures
PV	Photovoltaic

# Executive Summary

Solar power has become an important building block in Europe’s future energy mix. The technical reliability and financial stability of PV investments have to match the infrastructure quality requirements of established power generation facilities.

The Solar Bankability Guidelines try to provide recommendations for investors, banks, insurances and regulatory bodies to enhance the technical quality of PV investments.

For each stakeholder in a PV project the term “Solar Bankability” has a slightly different connotation (figure1):



Figure 1: Stakeholders of solar bankability assessment process

We suggest the following definition as common denominator for the term “Solar Bankability”:

**Solar Bankability is an active quality management process, where all stakeholders in the approval process of a PV project attempt to identify potential legal, technical and economical risks throughout the entire project life cycle. These risks need to be quantitatively and qualitatively assessed, managed and controlled. Despite a wide overlap in this quality management process, the focus and the assessment criteria will vary depending on whether the stakeholder represents an investor, a bank, an insurance or a regulatory body.**

Section 2 contains a short characterisation of technical project risks and their potential occurrence. Sections 3 to 6 provide guidelines for a four step risk management strategy.



Figure 2: Four step risk management strategy



However, this risk management strategy may vary depending on the size and type of the PV system. For utility-scale projects with a large investment budget the level of detail and the time intervals for system audits should be far more granular than for residential PV projects.

**Risk identification:** Section 3 introduces various checklists for the identification of technical risk, both for large-scale commercial/utility PV projects and small residential PV systems. Three of these checklists are included in Appendices 1 to 4.

**Risk assessment:** Section 4 describes different methodologies to assess technical risks. Both, the Cost Priority Number (CPN) methodology and the failure category methodology were developed in the course of the Solar Bankability project.

**Risk management:** Section 5 provides different risk management methods based on risk mitigation and risk transfer. Corrective and preventive measures can help to avoid and/or reduce technical risks. The transfer of risks can help to allocate these risks to those parties, which have the best control of each risk.

**Risk controlling:** Section 6 references the new financial market regulations introduced after the financial crisis in 2008. Institutional investors from the banking, insurance and investment funds industry face enhanced controlling and reporting requirements for large-scale PV investments. Also residential PV system owners are well advised to follow mitigation risk measures and to implement regular PV system check-ups.

# 1. Introduction

Historically, the term “Bankability” was coined during the credit crunch in the aftermath of the financial crisis in 2008. PV projects were typically financed by a 70 to 80% leverage. Banks often took over a gate keeper role in the project approval process. In the bankability assessment they introduced a systematic approach to identify legal, technical and economical risks of PV projects in order to ensure the debt service by predictable and stable cash flows over the entire debt financing period. The definition of „Bankability” varied from bank to bank and an uniform set of criteria did not exist [1].

With the decrease of interest rates and the introduction of a quantitative easing programme by the European Central Bank, liquidity became abundantly available. More and more PV projects became fully equity financed and the responsibility for an active risk management to ensure the quality of PV projects was more evenly distributed among the stakeholders involved in the project approval process. For each of these stakeholders the term „bankability“ has a somewhat different connotation (figure 3).

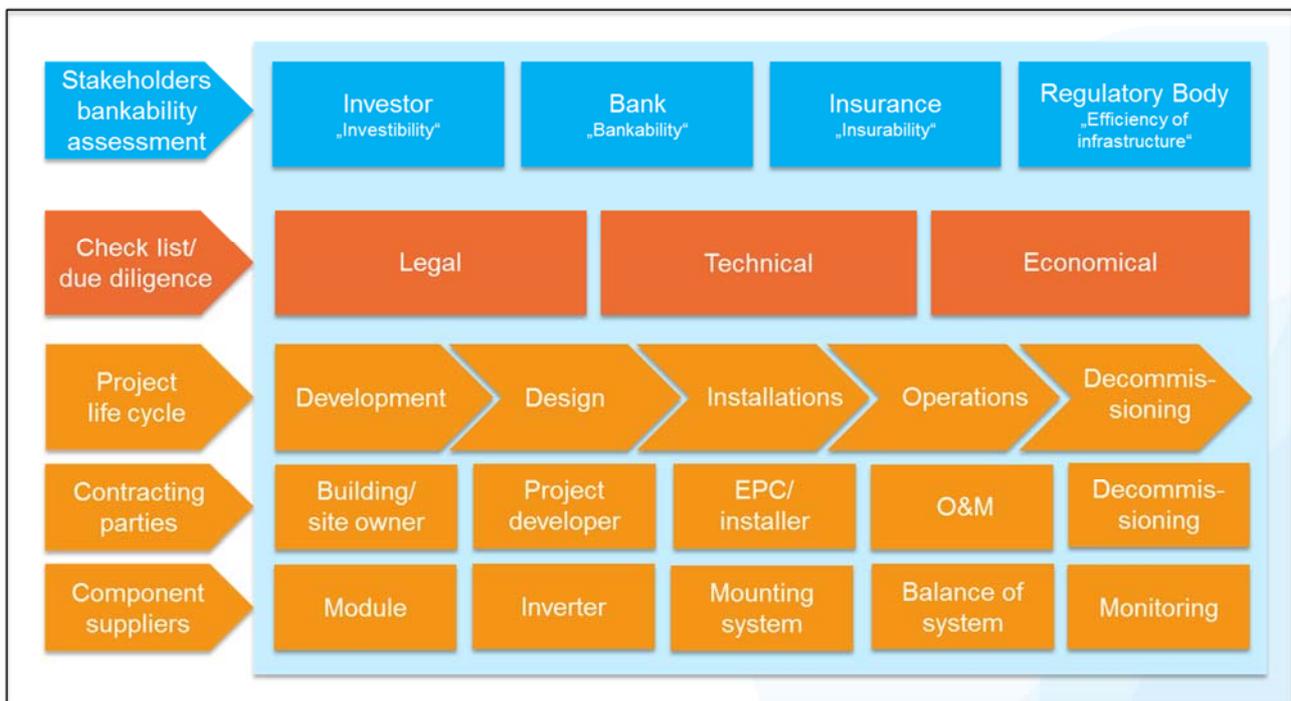


Figure 3: Solar bankability assessment from different stakeholders' perspectives

The investor or sponsor of the equity capital focuses on „investibility“ meaning stable and reliable cash flows in combination with potential tax incentives and measured by an adequate internal rate of return throughout the entire project life cycle.

The bank providing the debt capital focuses on „bankability“ meaning predictable and stable cash flows and measured by the debt service coverage ratio throughout the duration of the credit agreement.

The insurance focuses on the „insurability“ meaning low risks from external causes associated with potential risks from material defects or performance losses measured during the failure rate, the ratio of failure costs versus insurance premiums over the entire life cycle of the project.

The regulatory body focuses on the „efficiency of infrastructure“ meaning a cost-efficient and safe electricity generation along with stable grid operation measured by the levelised cost of electricity throughout the entire project life cycle. Unfortunately, for the time being, this focus is centred around costs aspects. As the share of solar electricity is increasing, governments will have to find more balanced approaches between the quantitative and qualitative aspects of efficiency [2].

As a more up to-date definition of the term “Solar Bankability” we therefore propose the following:

**Solar Bankability is an active quality management process, where all stakeholders in the approval process of a PV project attempt to identify potential legal, technical and economical risks throughout the entire project life cycle. These risks need to be quantitatively and qualitatively assessed, managed and controlled. Despite a wide overlap in this quality management process, the focus and the assessment criteria will vary depending on whether the stakeholder represents an investor, a bank, an insurance or a regulatory body.**

The budget available for the risk assessment depends on the size and the CAPEX of the PV project. The assessment of small residential PV systems is limited in budget and depth and therefore, is often based on check lists only. The assessment of commercial and utility-scale projects leaves room for larger budgets and a more thorough red flag or due diligence report.

However, parallel to the rapid decline of investment costs for PV systems the due diligence budgets have significantly decreased in recent years. In this context, it is important to underline that the responsibility for all project risks ultimately remains with the investor. He has to take a leading role in the quality management process and to ensure that sufficient budgets are allocated to cover all legal, technical and economical aspects in an adequate way.

## 2. Risk Characterisation

The scope of the Solar Bankability project is limited to technical PV risks only. Therefore, the assessment of legal and economical risks, which are not directly associated with technical risks are explicitly excluded from the subsequent elaboration.

The assessment of technical risks covers the entire project life cycle and involves all parties and associated contracts along with the corresponding components and associated suppliers (see figure 3).

Technical risks can arise from PV modules, inverters, and other mechanical or electrical components, as well as from system engineering, energy prediction, installation and operation. According to their root cause in the project life cycle they can be divided in two broad categories:

**Year 0 risks:** Their root cause falls in the project development phase during component production/testing and PV system design, planning and installation phase prior to commissioning.

**Operational risks:** Their root cause falls in the project operational phase after commissioning and before decommissioning.

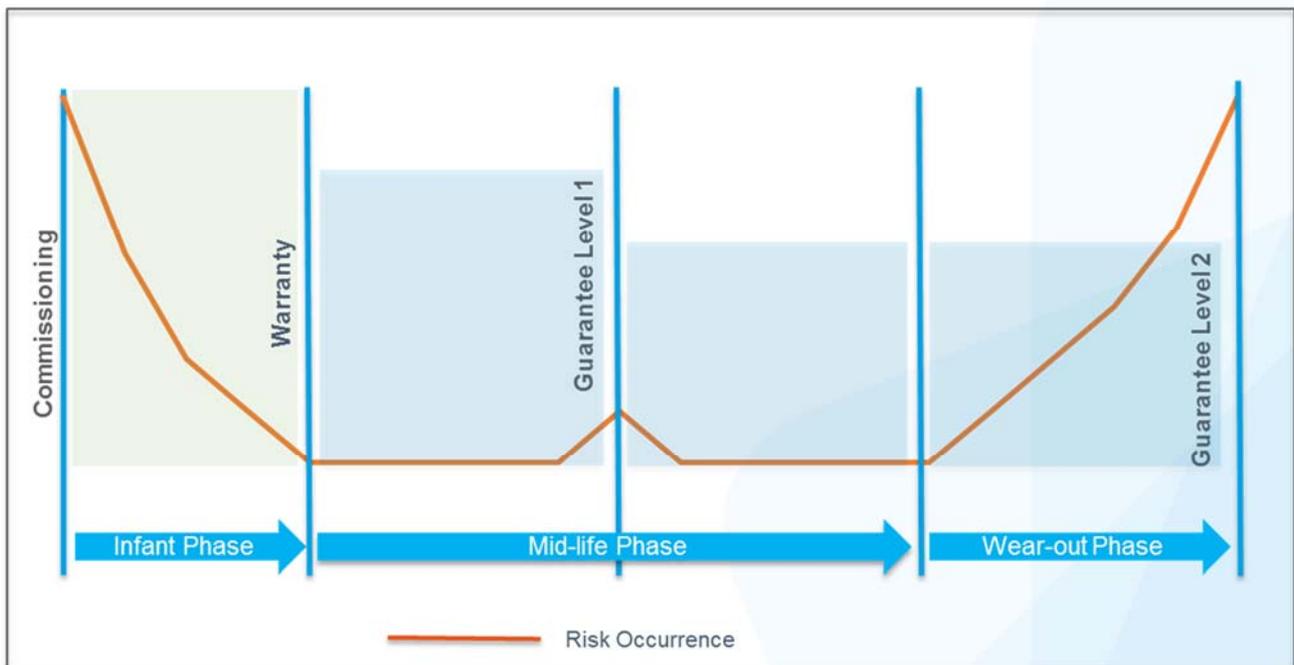


Figure 4: Occurrence of technical risks of PV systems during operation

The occurrence of risks during operation varies, but typically follows the bathtub shaped curve. During the system run-in in the infant phase of the project the risk occurrence is high. Afterwards it drops down during the mid-life phase under normal system operation showing a small „bump“ in the middle for components which are subject to a shorter life time, i.e. inverter fans and circuit boards. During the system wear-out phase the occurrence of failures increases significantly again. Since the majority of installed PV systems are less than 10 years in operation, limited statistical evidence is

available on the occurrence of technical risks towards the end of the PV system life time and how the occurrence will be influenced by the extension of project life cycles from 20 to up to 30 years (see figure 4 as qualitative schematics of risk occurrence).

Technical risks can be further distinguished according to the impact of risk:

**Uncertainty risks:** Risks associated with uncertainty will impact the performance of a PV system. Typical examples are the calibration of PV module flasher, irradiance estimates and PV module degradation. Their impact can be described by exceedance probabilities (e.g. P50, P90) and can be measured by a scenario analysis in the cash flow model as they will have an impact on the initial and lifetime yield assessment.

**Failure risks:** Risks associated with a material defect and/or a partial or complete PV system outage during operation. Their impact can be reflected in the cash flow model by the costs to detect and repair the failure and by the solar electricity losses due to the downtime of the PV system.

Technical risks very much depend on the individual framework conditions of the underlying PV system, i.e. system design and size, module technology and inverter configuration, site characteristics (whether ground or roof-top mounted), geographic and climatic conditions as well as international standards and local regulations in the year of installation and throughout plant operation.

Table 1: Technical risk matrix [3]

	Component 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	....	....	....	....	....



Technical risks can be mapped in a risk matrix with the main mechanical and electrical components of the PV system on one axis and the five different phases of the project life cycle on the other axis (see table 1). The Solar Bankability Report “Technical Risks in PV Projects” provides a detailed description of the risk matrix and identifies more than 140 specific technical risks.

Failure costs associated with technical risks are often backed by product warranties and performance guarantees. Two levels of recoverability have to be reflected:

**Component/performance risks:** Component and performance risks can be backed by product warranties and performance guarantees. Their recoverability will depend on the formulation of the respective warranty and guarantee conditions, the proof of failure requirements and the applicable jurisdiction.

**Contracting party/supplier risks:** Product warranties and performance guarantees must be backed by the respective contracting parties/suppliers. The recoverability will depend on the track record, profitability and ongoing operations of the respective parties. Claiming of warranty and guarantee costs can get complex and time-consuming if more than one jurisdiction is involved.

The PV industry is rather young, still highly innovative and shows a rather cyclical business behaviour. Compared to more matured industries such as automotive, the degree of quality management and standardisation along the entire PV value chain from component testing, production through design, installation and operation as well as decommissioning is much less advanced and often contains uncharted gaps.

**Gap risks:** In current industry practices technical gaps can still be identified along all phases of a PV project. International PV standards and regional building and grid codes need to be adopted. The specification of failures and appropriate testing methods need to be further developed. Results at standard testing conditions in the laboratory need to be translated into performance at actual field conditions.

Important technical gaps are addressed in the Solar Bankability report “Review and Gap Analysis of Technical Assumptions in PV Electricity Costs” [4].

### 3. Risk Identification

The identification of PV project risks is ideally carried out by an experienced technical expert from an independent third party. The scope of the risk analysis depends on the size of the project and the associated investment volume. It can vary from a full-fledged due diligence for a large utility-scale project to a red flag report for a commercial project or just a simple check list for a residential system.

The risk analysis should cover the entire project life cycle from project design and engineering, component procurement, installation, commissioning, operation and decommissioning. The most effective mitigation measure is the prevention of technical risks followed by the detection of technical risks as early as possible in order to avoid material defects, performance losses and potential personal hazards during the following phases of the project.

The risk identification process will depend on the technology, the type and the location of the PV project and might vary considerably between i.e. a ground-mounted PV utility project in Southern Italy or a roof-top residential PV system in Northern Germany. The process must be adopted to national standards, building codes and local craftsmanship regulations.

**Utility/commercial PV projects:** The scope of work for a full-fledged due diligence of large-scale PV projects might include a review of the design and engineering, component testing of modules, potential production audits at the module and inverter suppliers, audits during installation and commissioning, ongoing performance monitoring during operation and regular PV plant audits.

Risk identification for large-scale PV projects has reached a professional level and it pays off for the investor to allocate a sufficiently large budget early in the project and throughout operation. Several best practice guidelines and checklists have been developed in recent years. The Solar Bankability report “Best Practice Guidelines for PV Cost Calculations” contains three main checklists [6]:

1. Best Practice Checklist for EPC Technical Aspects (Appendix 1)
2. Best Practice Checklist for O&M Technical Aspects (Appendix 2)
3. Best Practice Checklist for Long-Term Yield Assessment (Appendix 3)

Three supplementary checklists are:

4. Checklist for As-Build Documents – Type and Details
5. Checklist for Record Control
6. Checklist for Reporting Indicators

A selection of further best practice guidelines and checklists from other sources has been included in the reference list [7,8,9,10,11,12].

**Residential PV projects:** In the past, residential PV roof-top systems were often sold under the umbrella of a risk-free and safe financial investment. Therefore, private house owners used to have little or no risk awareness. In some cases, these systems were installed under time pressure without

adequate PV training, qualification of staff and proper documentation. Like any other electrical installation, PV systems are subject to regular wear and ageing. Existing and newly formed trade and industry associations needed a couple of years to close the existing gaps of missing PV specific standards and regulations as well as to adopt their qualification and documentation requirements.

The German PV market serves as good example to illustrate these developments. As early as 2006 the “RAL Quality Assurance Association” introduced the PV quality label RALGZ 966 presenting standards for testing of PV components, design of PV systems, installation of PV systems, service and maintenance of PV systems and a check list for the commissioning of PV plants [13]. Unfortunately, only few of the early PV installers followed the voluntary commitment and the market penetration of the RAL PV label remained limited. In 2008, the German Solar Association BSW in cooperation with the Central Chamber of Electronics and Information Technology Trade ZVEH launched the “PV Passport” to check and document the design and installation of PV systems at the time of commissioning [14]. Until 2012 more than 1000 installers signed up for the PV Passport programme. In 2012, ZVEH launched the recurring “e-Check” PV Programme to complement the primary check-up of PV systems with a recurring check-up at a maximum recommended interval of four years [15]. In 2014, BSW in cooperation with ZVEH published the “PV Storage Passport” to account for the increasing number of PV systems with battery storage [16]. In 2016, the Quality Association for Solar and Roofing Technology (QVSD) introduced a quality check list for PV roof-top systems, which also covers technical risks associated with the interface of PV system and roofing system [17]. Combined market penetration of all these quality assurance schemes is estimated to be less than 10% for all new residential PV systems, which were installed in Germany in 2016. Many private house owners are still not aware that operators are legally responsible for the proper maintenance of electrical systems including PV systems. Industry and trade associations, consumer protection agencies, financing banks and insurances should support further market penetration of PV system check-ups and help to reduce technical risks associated with residential PV systems. This is especially important for safety issues.

An English version of the PV passport can be found in Appendix 4 of this report. The other checklists are only available in German and can be looked up under the respective reference number.

**Contracting parties:** An assessment of all contracting parties is essential in the risk identification process to ensure that the PV project will be backed by high quality components, professional workmanship and recoverable guarantees and warranties.

For utility/commercial PV projects the EPC, main component suppliers and the O&M (operation and maintenance) contractor should meet the following criteria (table 2):

**Table 2: Criteria for PV contractor risk identification [1]**

Dimension	Exemplary criteria
Company profile	Company size (e.g. revenue, market capitalization), international footprint, value chain positioning (upstream, downstream), legal structure, organization and management structure, age of company
Financial strength	Financial key performance indicators (e.g. balance sheet, profit and loss statement), provisions, shareholder structure, investors, investments
Production and product technology (only manufacturers)	Production sites, size and equipment used (manufacturer, maintenance intervals), operating material, production capacity and volumes, utilization rates, quality and environmental management, certificates, cost reduction potential, supplier, vertical integration
Performance record	Project portfolio, project track record/references, implementation strength, production ramp-up and efficiency
Sales and service	Delivery reliability, claim rate and management process, distribution network and channels, product guarantees, liabilities, insurances
Brand recognition	Awareness, reputation, strength of brand, experience, know-how, qualified staff, partnerships with banks, investors

For residential PV systems, the qualification of the installer should include electrical, mechanical, structural and roofing know-how and expertise. Only a minority of residential PV systems are properly documented in a comprehensive check list during commissioning. For most of these systems, an O&M contract with a regular check-up schedule is missing. An online monitoring system, which allows for a timely detection of failures and system outages, is therefore highly recommended.

The design, installation and operation of residential PV systems require specific skills from different trade associations. Therefore, special attention should be paid to potential gaps as described in table 3:

**Table 3: PV system skills vs. industry/trade associations in Germany**

	Electricity storage	PV system electrical	PV system mechanical	Roof system	Heat storage	Solarthermal system
Roof-top PV system		x	x	x		
Roof-top PV system with battery storage	x	x	x	x		
Roof-top PV system with heat storage		x	x	x	x	
German Solar Association	x	x	x		x	x
Central Chamber of Electronics and Information Technology Trade	x	x				
Central Chamber of Sanitary, Heating, Air Conditioning Trade					x	x
Central Chamber of Roofing Trade				x		
Quality Association Solar and Roofing Technology		x	x	x	x	x

PV system design
  PV trade/ industry associations

## 4. Risk Assessment

The research work in the Solar Bankability project pursues the objective to assess the economic impact of technical risks on various business models, their levelised cost of electricity and their profitability.

**Year 0 risks:** Year 0 risks during the planning phase of the PV project, such as irradiation estimates or PV module degradation, with an associated uncertainty have a direct impact on the utilisation factor and energy yield. Their economic impact can be assessed by a scenario analysis taking into account different exceedance probabilities. A detailed analysis of yield exceedance probabilities e.g. P50 or P90 can be found in the Solar Bankability report “Minimizing Technical Risks in Photovoltaic Projects” [22].

**Risks during operation:** Once the risks during operation materialise, they turn into failures and the associated economic impact can be assessed. In the Solar Bankability project two alternative methods have been analysed. The report “Technical Risks in PV Projects” provides a top-down statistical approach based on a “Cost Priority Number” or CPN [3]. The report “Financial Modelling of PV Risks” introduces a business model specific bottom-up approach [18].

The CPN method builds upon the parameters used in FMEA analysis such as the severity (S), the occurrence (O) and the detectability (D) of failures over a given timeframe and determines related costs due to downtime/power loss and repair/substitution:

$$CPN = C_{down} + C_{fix} \quad [€/kWp/year]$$

whereas  $C_{down}$  cost of downtime of the component,  
 $C_{fix}$  cost of fixing the failure.

More than 1 million failure cases in 746 PV plants with an installed capacity of around 422 MWp have statistically been evaluated to determine the Cost Priority Number in Euro per kWp and year for each technical risk. The data base allows to differentiate CPN numbers according to different market segments and system locations.

The respective report provides CPN for modules, inverters, mounting structure, cabling and combiner boxes (an example of CPN for PV modules is given in figure 5).

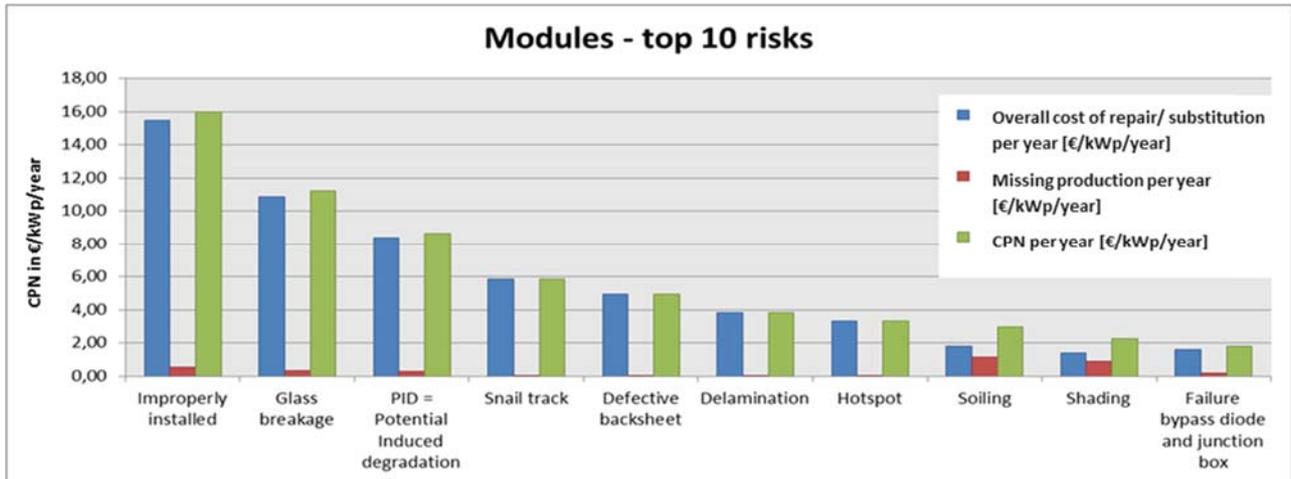


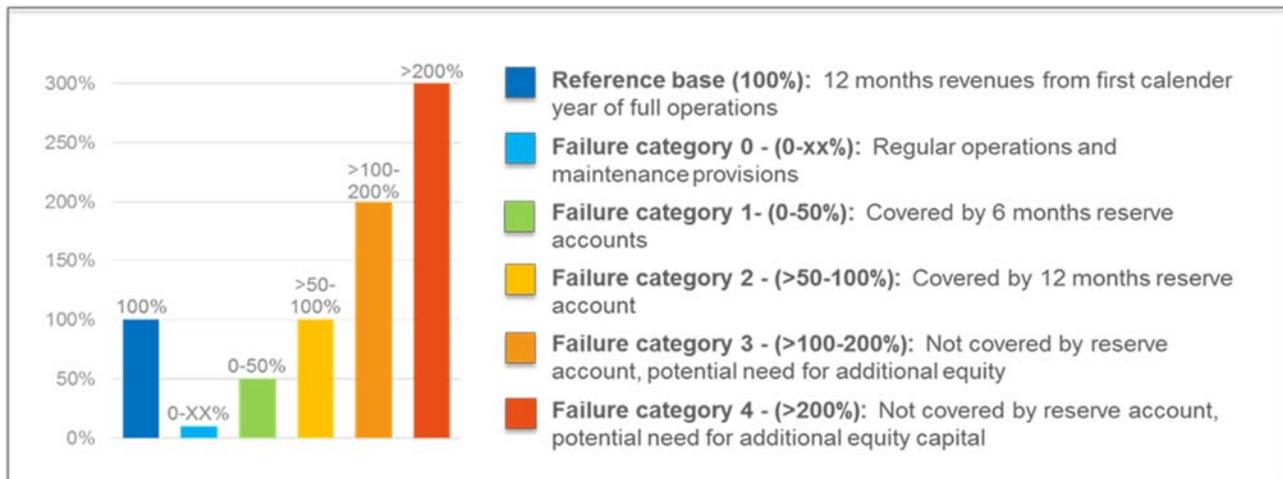
Figure 5: Top 10 CPNs for PV modules based on utility-scale PV projects

For the financial modelling of PV risks a detailed bottom-up approach based on actual failure costs for four different business models, two residential and two utility-scale models, in Germany, Italy and the UK have been evaluated to assess the economic impact on the respective cash flow models. In analogy to the CPN method, the severity, occurrence and detectability have been evaluated in a detailed calculations of the cost associated with each failure:

$$C_{fail} = C_{down} + C_{fix} \quad [€]$$

whereas  $C_{fail}$  cost of failure.

Different failure categories have been introduced to classify the economic impact on the cash flow model. The categories compare the failure impact with the 12 month revenues of the PV project in the first year of operation. The category structure follows the debt reserve account of 3, 6 or 12 months often required by banks in project financing to cover unpredicted project risks (figure 6).



**Figure 6: Definition of failure categories [18]**

The DiaCore study on “Risks in Renewable Energy Investments” [19] shows that technical risks represent only one dimension in an overall risk assessment. And that technical risks are of subordinate importance compared to other risks such as:

- Administrative risk,
- Grid access risk,
- Market design & regulatory risk,
- Policy design risk,
- Financing risk,
- Social acceptance risk,
- Sudden policy change risk.

In the rating methodology of professional rating agencies like Moody’s, only 20% of the overall weight is allocated to the technical risks in power generation projects [20].

## 5. Risk Management

The planning of a PV project should be complemented by a professional risk management plan. The plan should contain measures to prevent initial risks, to reduce their potential occurrence/impact and to transfer risks to other parties so that the residual risks, which have to be borne by the investor, can be minimised (figure 7).

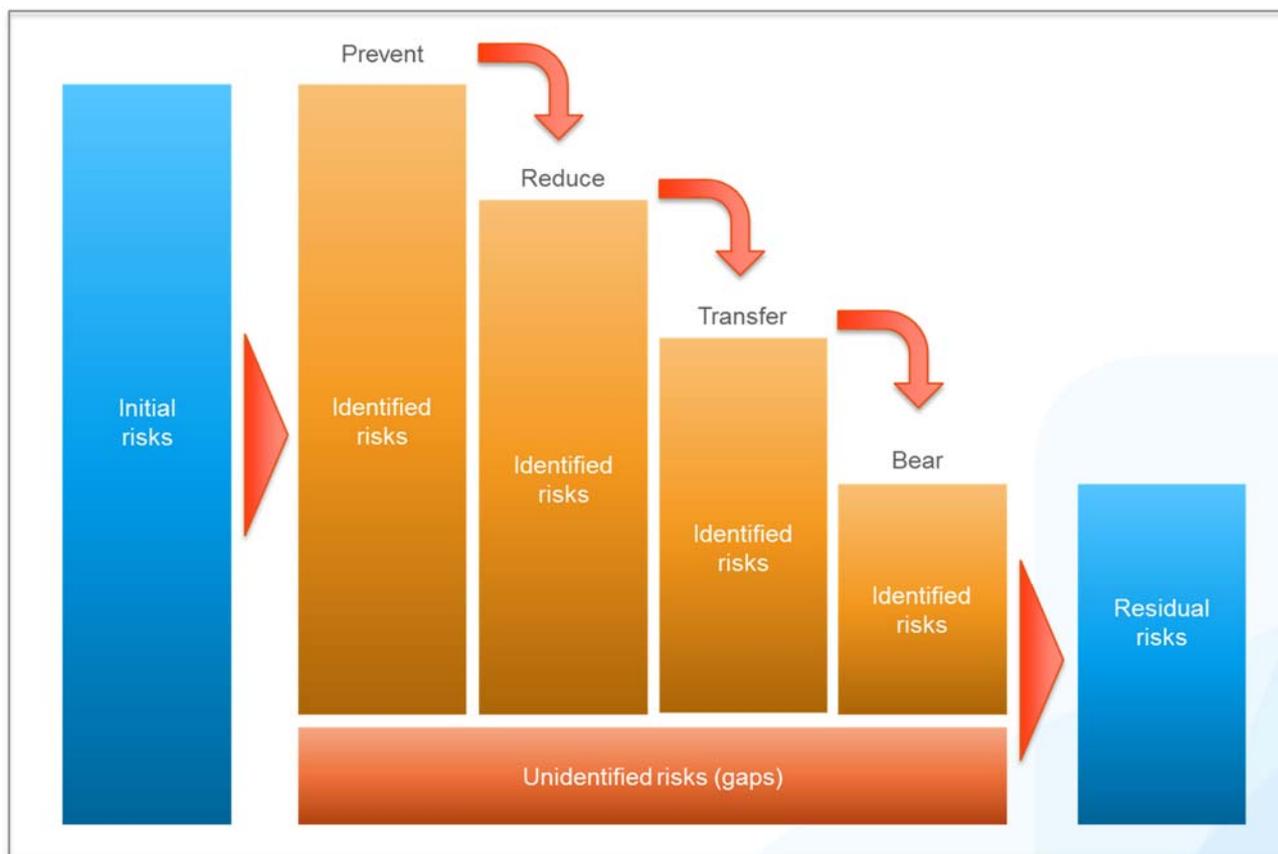


Figure 7: Potential risk management plan [21]

### 5.1 Risk Mitigation

There are two main categories of mitigation measures to prevent and reduce the potential occurrence and impact of initial risks.

**Preventive measures:** They are applied before the risk occurs in order to prevent it from happening. Due to early implementation, their costs are mostly related to CAPEX.

**Corrective measures:** They reduce higher losses and costs once the risk has already occurred. Their costs are mostly related to OPEX.

A list of all relevant risk mitigation measures is included in the Solar Bankability report “Minimising Technical Risks in Photovoltaic Projects” (table 4) [22]:

**Table 4: List of mitigation measures with description**

Mitigation measure	Description
<b>PV plant planning</b>	The planning of a PV plant requires taking assumptions of a set of input parameters in order to predict its final yearly energy production and its lifetime performance. This is usually done using specific software. Each input has a given uncertainty, depending on the availability and quality of the information that the planner has. PV projects, whose simulations are run in a context of little information on the input parameters, have the highest uncertainties of the output values, and therefore are more risky and is less attractive for PV investments.
<b>Reducing uncertainty (irradiation)</b>	Some of the main technical risks in lifetime energy yield calculations arise from the uncertainties related with the solar resource quantification and its long-term behaviour. These uncertainties affect directly the business plan and the investment decision can be compromised. Therefore, reducing these uncertainties can help to make the investment of the PV system more attractive.
<b>Reducing uncertainty (temperature)</b>	Use temperature coefficients or Ross coefficients from laboratory measurements or extrapolated from existing plants in similar conditions. When applying models to translate the available series of ambient temperature, use models that take also the influence of wind on module performance into consideration.
<b>Reducing uncertainty (degradation)</b>	Consider available research results on typical values of degradation rates according to technology and climate. Include spectral effects in modelling if possible to further reduce uncertainty.
<b>Component testing</b>	High-quality photovoltaic modules are subject to a number of requirements. First, they have to deliver the guaranteed rated power reliably. At the same time, the modules must be able to withstand an extremely wide range of environmental conditions. The modules must also be safe and durable, ensuring the system’s high yield over the long- term period. With component testing, the quality of the modules can be fully certified.
<b>Design review + construction monitoring</b>	The total number of detected failures due to wrong design or installation in the Solar Bankability database highlights the importance of this measure. In order for the PV project to meet the expectations of the investors regarding the profitability and life expectancy a number of actions have to be taken. Risks such as underperformance, warranty coverage, delay, cost overrun etc. are minimised after the application of this measure.

Mitigation measure	Description
<b>Qualification of EPC</b>	The qualification of EPC (engineering, procurement and constructions) is a preventive mitigation measure that will reduce the risk at an early stage of the PV project phase. EPC personnel shall have a high educational level as well as appropriate technical knowledge. Regular training schemes should be designed and available to EPC personnel for maintaining the high quality of staff and service provision.
<b>Advanced monitoring system</b>	An advanced monitoring system allows the early detection and diagnosis of faults. Early detection and diagnosis of faults during PV plant operation are essential in order to obtain and maintain the energy yield high. Early remediation of faults not only restores generation promptly but also avoids the occurrence of additional component failures and leads to reduction of O&M costs. The benefit of advanced monitoring is built up through reduced operational costs on one hand and additional revenues resulting from a higher performance ratio and higher availability on the other hand.
<b>Basic monitoring system</b>	A basic monitoring system typically allows the monitoring on plant level including device alarm collection and notifications. Furthermore, aggregation functionality on plant level for energy, irradiation and performance ratio are typically provided.
<b>Advanced inspection</b>	Advanced inspection relies on the use of techniques which go beyond visual inspection such as infrared imaging (IR) and electroluminescence imaging (EL), IV string analyser, etc.
<b>Visual inspection</b>	Visual inspection can establish whether any visual changes are occurring that may affect the performance of the principal components or reduce the effective life of the system or components providing data needed for planning maintenance and operation requirements. Through visual inspection technical risks with high occurrence can be typically detected (inverter polluted air filter, PV module glass breakage, broken connectors, etc).
<b>Spare parts management</b>	Spare parts management is a mitigation measure which has an impact in the initial investment and can be applied to several components of a PV plant. An effective spare parts management ensures the availability of the right amount and type of components, equipment, parts, etc. either on site or in warehouses or in manufacturers' consignment stocks, for prompt replacement in case of failure and/or to meet guarantees under O&M contracts.

In a cost benefit analysis, the impact of potential mitigation measures should be assessed along the life cycle of the project.

Two Solar Bankability reports provide a detailed analysis of risk mitigation scenarios consisting of single measures or a combination of measures. They come to the conclusion that preventive measures applied as early as possible in the project life cycle have the highest positive impact. Most effective measures are component testing, design review, qualification of EPC and monitoring systems for advanced fault detection [6, 21].

## 5.2 Risk Transfer

The ultimate responsibility of risks lies with the owner and operator of the PV project. However, through contracts, guarantees, warranties and insurances some of the risks can be transferred to other parties. The risks should be allocated to those parties, which have the best control of each risk (figure 8):

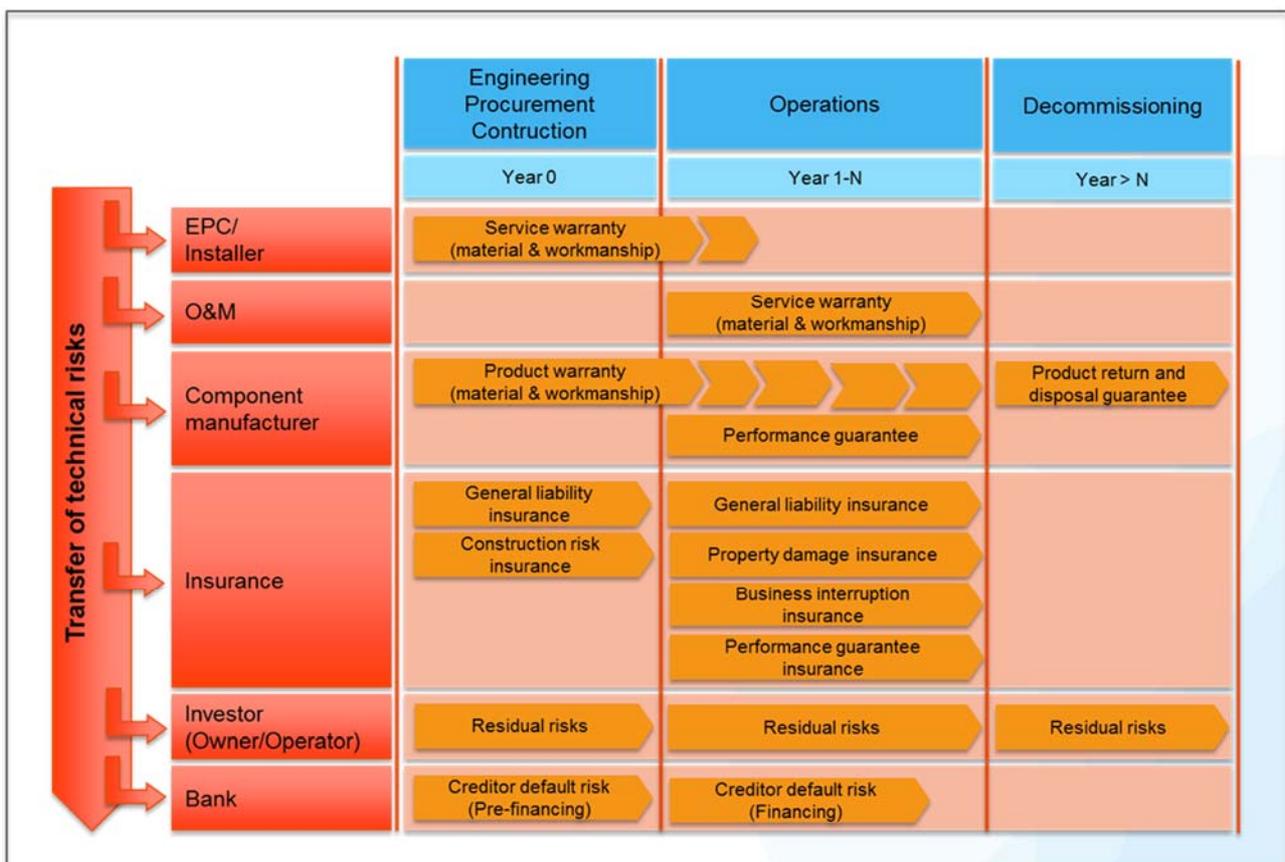


Figure 8: Transfer of technical risks

**EPC/Installer:** An EPC/installer contract should clearly specify the scope of work and the responsibilities of the EPC/installer during the engineering, procurement and construction phase of the PV project. The “Best Practice Checklist for EPC Technical Aspects” in Appendix 1 provides an overview of the items which should be considered in the contract. The services of the EPC/installer should be validated during commissioning of the PV system. The EPC/installer can be held

responsible for any material defect and/or workmanship failure during the warranty period. Depending on the type of contract and the national legal framework, the warranty period varies between one and two years [4]. In some cases, it can even reach five years. An on-site audit of the PV system is highly recommended prior to the expiration of the warranty period.

**O&M:** Most commercial and utility-scale PV systems are covered by an O&M contract. The O&M contract should clearly specify the scope of work and the responsibilities of a potential O&M contractor during the operational phase of the PV project. The “Best Practice Checklist for O&M Technical Aspects” in Appendix 2 provides an overview of the items which should be considered in the contract. The O&M contractor can be held responsible for any material defect and/or workmanship failure during the warranty period of services and materials provided by him. Many residential PV systems, however, lack any third party service and maintenance. Their owners have to be aware and comply with any legal or insurance requirements with respect to the operation, regular services and maintenance of the respective PV systems.

**Component manufacturer:** In most PV projects there is a supply contract between the component manufacturer and the EPC/installer. A direct supply contract with the investor is rather exceptional. Therefore, any claims against the manufacturer are usually handled indirectly via the EPC/installer. During the warranty period the manufacturer can be held responsible for any material and/or workmanship failures of his products. Tier one manufacturers often offer a voluntary extension of the legally required warranty period. This voluntary warranty period currently ranges between 10 to 12 years for PV modules and between 5 to 10 years for inverters. In addition to the product warranty, module suppliers normally offer a performance guarantee which ensures 90% of the name plate performance up to 10 years and 80% up to 25 years.

Historically, warranty and guarantee conditions were supply-side driven. In many cases it was not easy for investors to claim their warranty or performance guarantee. In recent years, consumer protection agencies have made several attempts to ensure better conditions for the investors. Investors should pay attention to the following potential pitfalls:

- The warranty and guarantee conditions should be clearly defined. Relevant criteria and potential test methods should be unambiguously specified and easy to implement.
- There is a potential conflict of interest in cases where the same contractor is responsible for the EPC/installer and the O&M service. An independent third party should carry out a PV plant audit before the end of the EPC/installer warranty period.
- A misalignment in the duration of the EPC/installer’s and the component manufacturer’s warranties might lead to potential conflicts. A longer EPC/installer and a shorter component manufacturer’s warranty period might force the EPC/installer into bankruptcy.
- Favourable manufacturer’s product warranty and guarantee conditions should cover the costs of dismantling, shipping, testing and disposal of worn-out products and the installation of the new product.

- Favourable manufacturer's product warranty and guarantee conditions should not only pay for the remaining value of the defective product, they should rather offer the replacement of the defective product by a new product and the compensation of potential production losses.
- The follow-up of warranty and guarantee claims is time, effort and cost consuming. In cases, in which international parties are involved, the complexity can significantly increase due to the involvement of multiple legislations.
- Investors should pay attention to potential contracting party risks. An increasing number of bankruptcies along the value chain of the PV industry have rendered potential warranty and guarantee conditions void.

**Insurance:** Insurance coverage for technical risks is available both during the project contraction and operational phase. The former phase can be covered by a general liability and a construction insurance. The latter phase can be covered by a general liability, a property damage, a business interruption, and optionally by a performance guarantee insurance. The coverage is offered for technical risks caused by external root causes such as storm, external surges, fire, theft, etc. Usually, the insurance includes a deductible which the PV system owner has to cover himself. The business interruption insurance covers revenues lost on power feed-in for the duration of a breakdown of up to 12 months. In recent years, insurers started to differentiate insurance premiums between new and used PV systems, with significantly higher premiums for aged PV systems. In case of an insurance claim, the insurer usually reserves the right to cancel the insurance.

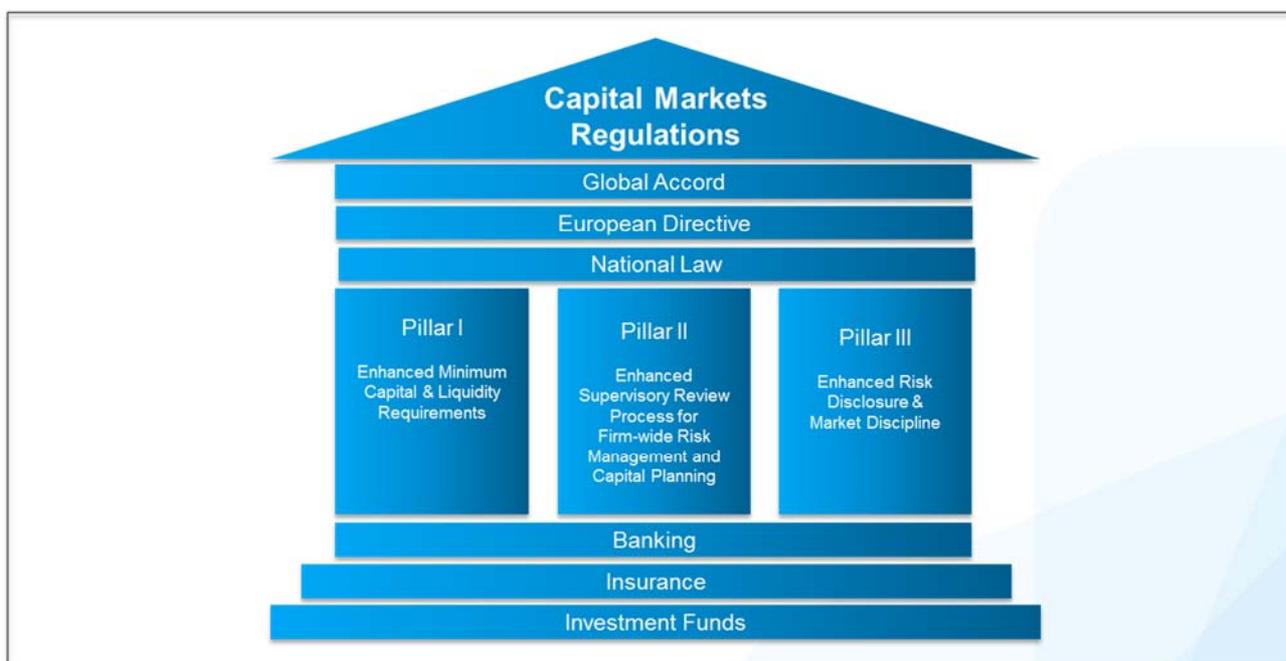
**Investor:** The investor in his role as owner and operator of the PV system has to bear all residual risks throughout the life cycle of the PV system, which are not covered by warranties, guaranties or insurances. Therefore, the investor should take an active role in the assessment of technical risks and not rely on the bankability assessment of the debt financing bank.

**Bank:** The bank bears the credit default risk during the pre-financing and the financing phase of a PV project. Usually, a thorough bankability assessment is performed to identify all relevant potential project risks. The risk structure of the project is reflected in the credit terms. The leverage ratio, the credit duration, the debt service reserve account and the interest rate are adjusted accordingly. In case any of the credit covenants are breached, the bank reserves the right to cancel the credit agreement.

## 6. Risk Control

In the aftermath of the financial crisis in the year 2008, new capital market requirements have been developed for institutional investors from the banking, insurance and investment funds industry in order to enhance the transparency and stability in global capital markets [18]. The new capital market framework is based on three pillars (figure 8) [23]:

- Pillar I: Enhanced minimum capital and liquidity requirements,
- Pillar II: Enhanced supervisory review process for firm-wide risk management and capital planning,
- Pillar III: Enhanced risk disclosure and market discipline.



**Figure 9: Three pillar model on new capital markets' regulations**

In a harmonised 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).

The regulations require institutional investors to introduce a hierarchically independent risk management function. This function is in charge of the firm-wide risk management including an ongoing risk controlling and a transparent risk reporting at least once a year. Institutional investors



can either enhance their own risk management organisation and build up an in-house team specialised in PV risk assessment or they can access external rating services, which are being offered by specialised consulting firms or international rating agencies.

The checking of technical risks for large commercial and utility-scale PV projects is often transferred to specialised owner's engineers. They ensure the professional supervision of the engineering, construction and commissioning of the PV plant and provide an ongoing risk monitoring during the operational phase with regular risk reporting at least once a year.

For residential PV systems the owner is responsible for the risk management. Most of these systems are not covered by a regular service and maintenance contract. Therefore, a regular check-up of the PV system is recommended at least every four years for PV systems equipped with an online monitoring system. For systems without an online monitoring system, the check-up intervals should not exceed two years [17].

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# Appendices

## Appendix 1: Best Practice Checklist for EPC Technical Aspects

☑/☒	Technical aspect & what to look for in the EPC contract
<b>A Definitions, interpretation</b>	
<input type="checkbox"/>	1. Is there a set of definitions of important terms provided and are those clear and understood by all stakeholders?
<b>B Contractual commitments</b>	
<input type="checkbox"/>	2. EPC contractor qualification
<input type="checkbox"/>	3. Responsibility and accountability
<input type="checkbox"/>	4. Date of ownership and risk transfer are defined and acceptable
<input type="checkbox"/>	5. Construction start date and end date are defined and acceptable
<input type="checkbox"/>	6. Plant Commercial Operation Date (COD) is defined and in line with FiT or PPA commencement dates
<input type="checkbox"/>	7. The EPC works should be carried in compliance with (non-exhaustive list) <ul style="list-style-type: none"> <li>• Grid code compliance: plant controls (e.g. ability for emergency shut-downs or curtailment according to grid regulations)</li> <li>• PPA compliance</li> <li>• Building permits (if applicable)</li> <li>• Environmental permits</li> <li>• Specific regulation for the site (e.g. vegetation management, disposal of green waste)</li> </ul>
<b>C Scope of work – engineering</b>	
<input type="checkbox"/>	8. Overall the scope of works for the EPC should be clearly defined. Which activities are included in the EPC services (is it a turnkey EPC)? Are they clearly defined?
<input type="checkbox"/>	9. The EPC should include Technical Specifications consisting of <ul style="list-style-type: none"> <li>• [Best practice] The operating environment is defined for:               <ul style="list-style-type: none"> <li>○ Minimum and maximum ambient temperature</li> <li>○ Maximum relative humidity</li> <li>○ Maximum altitude</li> <li>○ Local climate</li> <li>○ Local conditions (e.g., snowy, sandy, near sea/chemical source/corrosive/agricultural activity/purpose of building usage/etc.)</li> </ul> </li> <li>• Detail plant description on all major components including MV/HV equipment, monitoring, meteo stations, security and surveillance</li> </ul>

- Plant implantation schematic including not only the major components but also auxiliaries (electrical cabinet, substations etc.) and facilities (storage, office, guard house, fences, road access etc.)
- Single wire diagram
- Bill of materials of the major components
- Recommended minimum spare part lists (draft version of this information during EPC negotiation should be updated to the final version when the plant is completed and handed over)
- [Best practice] List of all applicable technical standards for major components (panels, inverters, electrical equipment) (non-exhaustive list)
  - CE Compliance
  - Panel: IEC61215, IEC61730, IEC61701, IEC62716, IEC62804, IEC62108 (CPV)
  - IR/EL: IEC60904-12 & 13
  - Inverter: IEC62109
  - Electrical equipment: IEC61000
  - Tracker: IEC62817, IEC62727
  - Design and installation: IEC TS 62548
  - Commissioning: IEC62446
  - Performance monitoring: IEC61724

10. Who is responsible for grid connection and the infrastructure to connect the PV plant to the grid (transformer, export lines, substation) is clearly defined

11. Site suitability (ground installation)
- Geotechnical and soil study
  - Any flood risk
  - Other constraints (chemical in the air, corrosive air, etc.)
- Site suitability (rooftop installation)
- Roof stability study
  - Structural requirements of roof and mounting structure (both static/snow load and dynamic/wind load)
  - Lightning protection requirement
  - Fire protection (PV system should not be built across fire protection walls); design should be in compliance with the building fire protection codes
  - Requirement for weathering protection (lifetime of roofing film)

12. If the site study has been done and the results have been shared with the owner and the EPC, the EPC contract should clearly acknowledge that the contractor has reviewed the results of the study and has designed the PV system taking into account the site conditions and constraints

<input type="checkbox"/>	13. For rooftop system, the roof should be weatherproof throughout operations of PV plant without major overhaul of roof laminate layer
<input type="checkbox"/>	14. Estimation of plant yield/production should follow best practice guidelines (see Annex C.3)
<input type="checkbox"/>	15. The plant design and estimated yield/production should be validated by third party
<b>D Scope of work – procurement</b>	
<input type="checkbox"/>	16. All major components should be visually inspected at delivery
	17. All modules should be tested for STC performance according to the IEC60904 standards at the factory and the test data should be submitted to the EPC contractor for verification [Best practice] All modules should be inspected with electroluminescence imaging camera at the factory and the test data should be submitted to the EPC contractor for verification
<input type="checkbox"/>	18. PV modules should be sampled and tested after delivery and before acceptance <ul style="list-style-type: none"> <li>• List of test (and criteria) should be included in the EPC contract</li> <li>• Tests are to be done by an accredited independent test laboratory</li> </ul>
<input type="checkbox"/>	19. [Best practice] Transportation and handling requirements on components should be specified
<input type="checkbox"/>	20. [Best practice] EPC contractor is required to perform factory inspection on the module factory
<input type="checkbox"/>	21. [Best practice] Negotiation of technical requirement in supply agreement (i.e. module) and warranty terms and conditions should involve inputs from technical advisors
<b>E Scope of work – construction</b>	
<input type="checkbox"/>	22. The EPC should include comprehensive protocol and training to its field workers on how to un-package and handle components properly
<input type="checkbox"/>	23. The installation of components should adhere the manufacturer’s guidelines when applicable
<input type="checkbox"/>	24. Regular construction monitoring by the owner (assisted by technical advisor) should be performed to check construction progress and quality (and for milestone payments)
<input type="checkbox"/>	25. Reporting of construction progress should be included in the contract
<input type="checkbox"/>	26. Health and safety, housekeeping and site security are defined as the responsibilities of the contractor during construction
<b>F Scope of work – administrative and others</b>	
<input type="checkbox"/>	27. Responsible party for securing the site use is clearly defined: <ul style="list-style-type: none"> <li>• For ground-mounted utility systems: land lease, land purchase, and land access</li> <li>• For commercial rooftop systems: roof lease, roof access</li> </ul>
<input type="checkbox"/>	28. Responsible party to obtain permits and authorizations to develop PV plant is clearly defined
	29. Any support required from the EPC contractors in permitting, grid connection etc. should be clearly defined
<input type="checkbox"/>	30. Is the contractor responsible to carry out or only support warranty and insurance claims management during the EPC period?
<b>G Manufacturer warranties</b>	

<input type="checkbox"/>	31. The terms and conditions of major components' manufacturer warranties are clearly defined <ul style="list-style-type: none"> <li>• Effective start and end date</li> <li>• Definition of defects</li> <li>• Claim procedure</li> <li>• The compensations proposed are reasonable and logical</li> <li>• Exclusions</li> <li>• Provision to allow for the involvement of third party expert during technical dispute</li> <li>• Transferability</li> </ul>
<input type="checkbox"/>	32. The warranty timelines should be in line with the EPC warranty timelines
<input type="checkbox"/>	33. Check if the jurisdiction of the warranty allows it to be legally enforceable
<input type="checkbox"/>	34. [Best practice] Are there additional insurances (transportation damages, e.g.) from either the EPC contractor or component manufacturer?
<b>H EPC warranty and Defect Liability Period (DLP)</b>	
<input type="checkbox"/>	35. Provide warranty of Good Execution of Works
<input type="checkbox"/>	36. The EPC contract shall provide at minimum 2-year EPC warranty from the date of plant take-over
<input type="checkbox"/>	37. The DLP duration coincides with the EPC and component manufacturer warranty duration
<input type="checkbox"/>	38. During this DLP, the EPC contractor is responsible to repair faults or defect at its own cost, or an arrangement has been made with the O&M contractor to execute this. For the latter, clear scope of work ownerships must be aligned to prevent avoidance of responsibilities
<input type="checkbox"/>	39. The party responsible to maintain the PV plant after take-over and before the end of DLP is clearly defined
<b>I Key performance indicators (KPIs) and guarantees</b>	
<input type="checkbox"/>	40. The EPC contract should have key performance indicators for two aspects <ul style="list-style-type: none"> <li>• Completion timeline: guaranteed completion date</li> <li>• System performance and quality: guaranteed performance ratio (PR) or guaranteed output</li> </ul>
<input type="checkbox"/>	41. The guaranteed PR or output should be calculated in a long-term yield estimation exercise using correct technical assumptions, i.e. all relevant losses and uncertainties
<input type="checkbox"/>	42. Liquidated damages (LD) or penalties should be assigned in the contract in case the guaranteed KPIs are not met
<input type="checkbox"/>	43. Completion delay LDs should be in line with the project revenue loss due to lateness in project entering operation. The LD is commonly a % of EPC price for each day of delay
<input type="checkbox"/>	44. Performance LDs should be in line with the project revenue loss when the system is not meeting the guaranteed performance level. The LD is commonly a % of EPC price for each point of PR or output below the guaranteed value
<input type="checkbox"/>	45. Maximum amount of LD (LD cap) to limit contractor's liability is usually included in the EPC contract. E.g., delay LD and performance LD could each be capped at 20% of the EPC contract price and the combined cap is 30% of the EPC contract price

## **J** Commissioning and acceptance

- 46. The EPC contract should include plant provisional and final commissioning
- 47. Short term performance test should be carried out after the PV system completes the construction phase
- 48. Provisional test set-up should include appropriate:
  - Duration of the test
  - Irradiance threshold
  - Monitoring system, including measurement sampling rate and averaging method
- 49. The calculation method for the key performance indicator for provisional acceptance should account for short-term effect on temperature and irradiance
- 50. Final acceptance plant performance should be carried out after the plant has been in operation for a representative period of time (2 years after provisional acceptance)
- 51. Final performance test set-up should include appropriate
  - Irradiance threshold
  - Monitoring system, including measurement sampling rate and averaging method
- 52. The calculation method for the key performance indicator for final acceptance should account for:
  - Annual degradation
  - Plant availability
- 53. Measurement of irradiance to assess plant performance
  - Irradiance measurements
  - Measurement in the POA according to the Secondary Standard or First Class quality classification (ISO9060:1990)
  - Minimum requirement: one measurement device (pyranometer of high quality)
  - [Best practice] At least 2 pyranometers
  - If different array orientations, one pyranometer per orientation – careful assignment for proper calculation of PR and yield
  - Sensors placed at the least shaded location
  - Sensors installed according to manufacturer's guidelines
  - Preventative maintenance and calibration according to manufacturer's guidelines
  - Set irradiance to be recorded with averages of 15 min (minimum requirement) or 1 min and less (best practice)
  - High quality satellite-based data to complement terrestrial measurements [best practice] – mainly for monthly and annual values and not daily since the RMSE is high (8-14%)
  - Minimum requirements for satellite data: hourly granularity or 15 min. Set data to be retrieved once per day at least
- 54. Measurement of irradiance to assess plant performance
  - Temperature sensor properly installed according to manufacturer's guidelines

- Use of stable thermally conductive glue to the middle of the backside of the module in the middle of the array, in the center of the cell away from junction box
- Accuracy should be  $\leq \pm 1$  C including signal conditioning
- For large systems, different representative positions for installing the sensor should be considered: module at the center of the array and at the edge of this module where temperature variations are expected



55. Inverter measurement to assess plant performance

- AC level: energy and power data should be collected
- Energy data should be cumulative values over the lifetime of the inverter
- Collect all inverter alarms – important to plan your maintenance activities (corrective and preventative)
- Monitor and manage control settings at the inverter level and the grid injection level
- DC input measurements  $< 1$ s sampling and  $< 1$ min averaging
- DC voltage to be measured and stored separately for allowing MPP-tracking and array performance problems
- [Best practice] measure all parameter from the inverters including internal temperature, isolation level etc.



56. Energy meter

- Collection of energy meter data by the monitoring system in daily basis and with 15 min granularity
- High accuracy energy meter is required – uncertainty of  $\pm 0.5\%$  for plants  $> 100$  kWp
- The above point can be considered as best practice for plants smaller than 100 kWp



57. Plant visual inspection should be carried out during acceptance test

[Best practice] The visual inspection uses advanced tools such as IR camera



58. As part of the plant hand-over process, the EPC contractor must provide (non-exhaustive list)

- A complete set of as-built documentation (IEC62446, see Annex C.4 for complete set)
- Recommended minimum spare parts list

## Appendix 2: Best Practice Checklist for O&M Technical Aspects

☑/☒	Technical aspect & what to look for in the O&M contract
<b>A Definitions, interpretation</b>	
<input type="checkbox"/>	1. Is there a set of definitions of important terms provided and are those clear and understood by all stakeholders?
<b>B Purpose and responsibilities</b>	
<input type="checkbox"/>	2. Is the fundamental purpose (goals) of the contract clearly defined?
<input type="checkbox"/>	3. Are the roles and responsibilities (and boundary conditions) of the multiple stakeholders within the contract clear and understood?
<b>C Scope of works – environmental, health and safety</b> Note: The Asset Owner has the ultimate legal and moral responsibility to ensure the health and safety of people in and around the solar plant and for the protection of the environment around it. The practical implementation is normally subcontracted to the O&M contractor.	
<input type="checkbox"/>	4. Environment <ul style="list-style-type: none"> <li>• Regular inspection of transformers and bunds for leaks (according to the annual maintenance plan)</li> <li>• Recycling of broken panels and electric waste</li> <li>• Sensible water usage for module cleaning</li> <li>• Proper environmental management plan in place</li> </ul>
<input type="checkbox"/>	5. Health and safety (H&S) <ul style="list-style-type: none"> <li>• Properly controlled access and supervision in the solar plant – necessary boundaries and site restrictions</li> <li>• Proper induction to ensure awareness of risks and hazards</li> <li>• Proper training and certification on the specifics of a PV plant and voltage level</li> <li>• Hazard identification/marketing</li> <li>• Wiring sequence marking</li> <li>• H&amp;S legislation available</li> <li>• Established personal protective equipment (PPE) (not exhaustive list): safety shoes, high visibility clothing, helmet, gloves (and/or insulated gloves), slash masks and glasses (depending on the site), fire retardant and/or arc flash rated PPE where necessary</li> <li>• Calibrated and certified equipment (full documentation available)</li> </ul>
<b>D Scope of works – operations</b>	
<input type="checkbox"/>	6. Documentation Management System (DSM) <ul style="list-style-type: none"> <li>• As-built documentation / IEC62446 (see Annex C.4)               <ul style="list-style-type: none"> <li>○ Site information</li> <li>○ Project drawings</li> </ul> </li> </ul>

- Project studies
- Studies according to national regulation requirements
- PV modules
- Inverters
- Medium voltage / inverter cabin
- MV/LV transformer
- HV switchgear
- UPS and batteries
- Mounting
- Management and control
  - Define type of storage (physical or/and electrical)
  - Ensure electronic copy of all documents
  - Ensure controlled access to documents
  - Ensure authorization for modifications – keep a logbook on name of person who modified the document, date of modification, reason for modification and further information e.g. link to the work orders and service activities
  - Ensure history of the documents (versioning)
- Record control (see Annex C.5)

7. [Best practice] Predictive maintenance
- Define scope of this cluster, the type of performance analysis, the level (portfolio level, plant level, inverter level, string level)
  - Define the monitoring requirements needed to perform predictive maintenance, provide basic trending and comparison functionality

8. Power generation forecasting
- Ensure a service level agreement with the forecast provider
  - Define the purpose and consequently the requirements for power forecasting (e.g. time horizon, time resolution, update frequency)

9. Reporting (see Annex C.6)

10. Regulatory compliance
- Grid code compliance: plant controls (e.g. ability for emergency shut-downs or curtailment according to grid regulations)
  - PPA compliance
  - Building permits (if applicable)
  - Environmental permits
  - Specific regulation for the site (e.g. vegetation management, disposal of green waste)

<input type="checkbox"/>	11. Management of change: define responsibilities and involvement when PV plant needs to be adjusted after the Commercial Operation Date: e.g. spare parts, site operation plan, annual maintenance plan etc.
<input type="checkbox"/>	12. Warranty management <ul style="list-style-type: none"> <li>• Warranty of Good Execution of Works</li> <li>• Warranty of Equipment</li> <li>• Performance Warranty: agree on reporting period</li> <li>• Classification of anomalies and malfunctions: Pending Works, Insufficiencies, Defects, Failure or malfunction of equipment</li> </ul>
<input type="checkbox"/>	13. Insurance claims management
<b>E</b>	<b>Scope of works – maintenance</b>
<input type="checkbox"/>	14. Inclusion of an adequate Preventive Maintenance Plan
<input type="checkbox"/>	15. The minimum requirements for preventative tasks and their frequency follow the manufacturer's guidelines when applicable
<input type="checkbox"/>	16. The minimum requirements for preventative tasks and their frequency should respect relevant national standards
<input type="checkbox"/>	17. Corrective maintenance (CM) <ul style="list-style-type: none"> <li>• Fault diagnosis (troubleshooting)</li> <li>• Repair and temporary repairs</li> <li>• Agreed response times and/or minimum repair times</li> <li>• Clear definition of "boarders" and "limitations" of CM tasks, especially with preventative maintenance and extraordinary maintenance. Definition of yearly cap of CM works (when applicable)</li> </ul>
<input type="checkbox"/>	18. Extraordinary maintenance <ul style="list-style-type: none"> <li>• Define what is included in this cluster <ul style="list-style-type: none"> <li>○ Damages that are a consequence of a Force Majeure event</li> <li>○ Damages as a consequence of a theft or a fire</li> <li>○ Serial defects on equipment, occurring suddenly and after months or years from plant start-up</li> <li>○ Modifications required by regulatory changes</li> <li>○ Agreed interventions for reconditioning, renewal and technological updating</li> </ul> </li> <li>• Define the rules on how to execute tasks and prepare quotations – ways of payment</li> </ul>
<input type="checkbox"/>	19. Additional services: define what is included in this cluster and how this service is paid (non-exhaustive list) <ul style="list-style-type: none"> <li>• Module cleaning</li> <li>• Vegetation management</li> <li>• Road maintenance</li> </ul>

- Snow removal
- Pest control
- Waste disposal
- Maintenance of buildings
- Perimeter fencing and repairs
- Maintenance of security equipment
- String measurements – to the extent exceeding the agreed level of preventative maintenance
- Thermal inspections – to the extent exceeding the agreed level of preventative maintenance
- Meter weekly/monthly readings and data entry on fiscal registers or in authority web portals for FIT tariff assessment (where applicable)

## **F** Scope of works – data and monitoring

- 20. Irradiance measurements
  - Measurement in the POA according to the Secondary Standard or First Class quality classification (ISO9060:1990)
  - Minimum requirement: one measurement device (pyranometer of high quality)
  - [Best practice] At least 2 pyranometers
  - If different array orientations, one pyranometer per orientation – careful assignment for proper calculation of PR and yield
  - Sensors placed at the least shaded location
  - Sensors installed according to manufacturer’s guidelines
  - Preventative maintenance and calibration according to manufacturer’s guidelines
  - Set irradiance to be recorded with averages of 15 min (minimum requirement) or 1 min and less (best practice)
  - High quality satellite-based data to complement terrestrial measurements [best practice] – mainly for monthly and annual values and not daily since the RMSE is high (8-14%)
  - Minimum requirements for satellite data: hourly granularity or 15 min. Set data to be retrieved once per day at least
- 21. Module temperature measurements
  - Temperature sensor properly installed according to manufacturer’s guidelines
  - Use of stable thermally conductive glue to the middle of the backside of the module in the middle of the array, in the center of the cell away from junction box
  - Accuracy should be  $\leq \pm 1$  C including signal conditioning
  - For large systems, different representative positions for installing the sensor should be considered: module at the center of the array and at the edge of this module where temperature variations are expected
- 22. Local meteorological data

	<ul style="list-style-type: none"> <li>• [Best practice] Ambient temperature and wind speed with sensors installed according to manufacturer's guidelines</li> <li>• Ambient temp with shielded thermometer e.g. PT100</li> <li>• Wind speed with anemometer at 10 m height above ground level</li> <li>• For large plants &gt;10 MW automated data from an independent nearby meteo source to smooth local phenomena and installation specific results</li> </ul>
<input type="checkbox"/>	<p>23. String measurements</p> <ul style="list-style-type: none"> <li>• If not DC input current monitoring at inverter level, then current monitoring at string level is recommended – depending on module technology, combined strings (harnesses) can help reducing operating costs</li> <li>• [Best practice] Increase up-time for timely detection of faults: 1 sec sampling and 1 min averaging at data logger, maximum two strings current measurement in parallel</li> </ul>
<input type="checkbox"/>	<p>24. Inverter measurement</p> <ul style="list-style-type: none"> <li>• AC level: energy and power data should be collected</li> <li>• Energy data should be cumulative values over the lifetime of the inverter</li> <li>• Collect all inverter alarms – important to plan your maintenance activities (corrective and preventative)</li> <li>• Monitor and manage control settings at the inverter level and the grid injection level</li> <li>• DC input measurements &lt;1s sampling and &lt;1min averaging</li> <li>• DC voltage to be measured and stored separately for allowing MPP-tracking and array performance problems</li> <li>• [Best practice] measure all parameter from the inverters including internal temperature, isolation level etc.</li> </ul>
<input type="checkbox"/>	<p>25. Configuration</p> <ul style="list-style-type: none"> <li>• In cases of change of O&amp;M contractor (or recommissioning of the monitoring system), the configuration of the monitoring system and the data loggers should be checked</li> <li>• [Best practice] if technically available, auto-configuration is recommended – e.g. automatic collection of inverter and sensor IDs and labels</li> <li>• Back up of the configuration should be in place</li> </ul>
<input type="checkbox"/>	<p>26. Energy meter</p> <ul style="list-style-type: none"> <li>• Collection of energy meter data by the monitoring system in daily basis and with 15 min granularity</li> <li>• High accuracy energy meter is required – uncertainty of <math>\pm 0.5\%</math> for plants &gt;100 kWp</li> <li>• The above point can be considered as best practice for plants smaller than 100 kWp</li> </ul>
<input type="checkbox"/>	<p>27. AC circuit / protection relay</p> <ul style="list-style-type: none"> <li>• [Best practice] Monitor the AC switch position for (sub) plants. Read the alarms from the protection relay via communication bus if possible</li> </ul>
<input type="checkbox"/>	<p>28. Data loggers</p>

- Sufficient memory to store at least one month of data
- Historical data should be backed up
- After communication failure, the data logger should resend all pending information
- The entire installation (monitoring system, signal converters, data loggers, measurement devices) should be protected by a UPS
- [Best practices] Memory to store at least six months of data and full data backup in the cloud. Separate remote server to monitor the status of the data loggers and inform the operations. The system should be an open protocol to allow transition between monitoring platforms. If possible, reboot itself once per day (during night time) to increase reliability



#### 29. Alarms

- Minimum requirement: alarms sent by email (non-exhaustive list)
  - Loss of communication
  - Plant stop
  - Inverter stop
  - Plant with low performance
  - Inverter with low performance (e.g. due to overheating)
- [Best practice] (non-exhaustive list)
  - String without current
  - Plant under UPS operation
  - Intrusion detection
  - Fire alarm detection
  - Discretion alarm (or alarm aggregation)



#### 30. Dashboard / web portal

- Minimum requirements for features of the monitoring system (non-exhaustive list)
  - Web portal accessible 24h/365d
  - Graphs of irradiation, energy production, performance and yield
  - Downloadable tables with all the registered figures
  - Alarms register
- [Best practices] (non-exhaustive list)
  - User configurable dashboard
  - User configurable alarms
  - User configurable reports
  - Ticket management



#### 31. Data format

- Data format of recorded files according to IEC61724 – clearly documented
- Data loggers should collect alarms according to manufacturer's format

- 32. Communication from the site to the monitoring servers
  - Best network connectivity with sufficient bandwidth according to the available monitoring system
  - DSL connection preferred if available at the PV site – industrial routers recommended
  - [Best practice] GPRS-connection as back up
  - For sites >1 MW it is advised to have a LAN connection and as an alternative an industrial router that allows for GPRS or satellite communication back-up in case the LAN connection fails. A router with an auto-reset capability in case of loss of internet connection is recommended
  - Data security should be ensured: as minimum requirements loggers should not be accessible directly from the internet or at least be protected via a firewall. Secure and restrictive connection to the data server is also important
  - Communication cables must be shielded and protected by direct sunlight
  - Physical distance between DC or AC power cables and communication cables should be ensured
  - Cables with different polarities must be clearly distinguishable (label or color) for avoiding polarity connection errors

#### **G Scope of works – spare parts management**

- 33. Definition of ownership and responsibility of insurance
- 34. Define separate list of consumables if applicable (e.g. tools and fuses)
- 35. Stocking level: consider initial EPC list and the following parameters
  - Frequency of failure
  - Impact of failure
  - Cost of spare part
  - Degradation over time
  - Possibility of consignment stock with the manufacturer
- 36. Location of storage/warehouse
  - Proximity to the plant
  - Security
  - Environmental conditions
- 37. List of minimum spare parts (non-exhaustive list)
  - Fuses for all equipment (e.g. inverter, combiner boxes etc.) and fuse kits
  - Modules
  - Inverter spares (e.g. power stacks, circuit breakers, contactor, switches, controller board)
  - UPS
  - Voltage terminations
  - Power plant control spares

- Transformer and switchgear spares
- Weather station sensors
- Motors and gearboxes for trackers
- Harnesses and cables
- Screws and other supply tools
- Security equipment (e.g. cameras)

## **H** Scope of works – plant security

- 38. Define protective measures for the plant
  - Security protocol in place
  - Video monitoring
  - Alerting system
  - Fencing or barriers
  - Warning signs and notices
  - Security pad codes and passwords
  - Back up communication in case of vandalism

## **I** Key performance indicators (KPIs)

- 39. Plant KPIs
  - Availability
  - Energy-based availability
  - Performance Ratio
  - Energy Performance Index
- 40. O&M contractor KPIs
  - Reaction time
  - Reporting
  - O&M contractor experience
  - Maintenance effectiveness and maintenance support efficiency
- 41. Security and surveillance of PV plant
  - On-site or remote
  - Around the clock coverage (24h/365d)
  - On-site patrol, security camera
  - On-site intervention time upon alarm etc.

## **J** Contractual commitments

- 42. Qualification of parties involved: Owner's Engineer, O&M contractor, monitoring, security firm
- 43. Responsibility and accountability
- 44. Bonus schemes and liquidated damages

## Appendix 3: Best Practice Checklist for Long-Term Yield Assessment

☑/☒	Technical aspect & what to look for in the LTYA
<b>A Solar resource assessment</b>	
<input type="checkbox"/>	1. Only reliable solar irradiation data sources should be used and the name(s) and version(s) must be clearly stated. Data source(s) used must be able to provide uncertainty estimations and ideally have been extensively validated
<input type="checkbox"/>	2. The period covered by the solar irradiation data source(s) used must be reported. Only data sources with more than 10-year recent data should be used for LTYA calculations
	3. The effect of long-term trends in the solar resource should be analyzed. In the presence of such trends, the long-term solar resource estimation should be adjusted to account for this effect
<input type="checkbox"/>	4. The use of site adaptation techniques is recommended to reduce the uncertainty. A measurement campaign of at least 8 months and ideally one full year is recommended
<b>B PV yield modelling</b>	
<input type="checkbox"/>	5. The PV modeling software and the specific version used must be clearly stated in the report
<input type="checkbox"/>	6. If in-house software is used, the name(s) and version(s) must also be stated
<input type="checkbox"/>	7. All assumptions (e.g. soiling losses, availability, etc.) and sub-models used (e.g. transposition model) must be clearly stated
<b>C Degradation rate and behaviour</b>	
<input type="checkbox"/>	8. The degradation rate(s) used for the calculations must be clearly stated in the report. It is recommended to differentiate between first year effects and yearly behavior over project lifetime
<input type="checkbox"/>	9. Degradation behavior assumption (e.g. linear, stepwise, etc.) over time should be clearly stated and ideally backed up with manufacturer warranties
<input type="checkbox"/>	10. If specific manufacturer warranties are available (e.g. module warranty document or sales agreement), these can be used to fine tune the lifetime degradation calculation
<b>D Uncertainty calculation</b>	
<input type="checkbox"/>	11. All steps in the long-term yield calculation are subject to uncertainties. All uncertainties should be clearly stated and references must be provided in the report
<input type="checkbox"/>	12. Special attention must be paid to the solar resource related uncertainties as these are among the most important elements in the contribution to the overall uncertainty
<input type="checkbox"/>	13. If special methods are used to reduce some uncertainties e.g. site adaptation techniques, these should be clearly documented and ideally backed up with scientific validation
<input type="checkbox"/>	14. Special care must be taken when classifying each uncertainty as either systematic or variable (stochastic) since these are treated differently in overall lifetime uncertainty calculations
<input type="checkbox"/>	15. When possible, exceedance probabilities (e.g. P90) for each uncertainty must be calculated using empirical methods based on available data instead of assuming normal distribution for all elements

## Appendix 4: PV Passport



Annexes to PV Passport No. \_\_\_\_\_ - \_\_\_\_\_ - \_\_\_\_\_



PHOTOVOLTAIC SYSTEM	
<b>Installed system capacity</b>	<b>System operator / Contractor</b>
Nominal output of all modules _____ kWp	_____ (First and last name or name of company)
<b>Alignment and roof pitch</b>	Street, house number _____
<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <p>Alignment</p> </div> <div style="text-align: center;"> <p>Roof pitch</p> </div> </div> <p>Please circle the appropriate degree</p>	Postal code, city _____
	<b>Location of system (if different from above)</b>
	Building/property owner (first and last name or name of company) _____
	Street, house number _____
	Postal code, city _____
<b>Photo / description of system</b>	<b>Commissioning, metering system</b>
(Type of building, sloped roof, flat roof, contiguous system or divided into sections, rooftop/integrated, ...)	Date of commissioning: _____
	Feed-in / reference meter No.: _____
	Meter reading at handover _____ kWh
	PV measuring device, meter No.: _____
	Meter reading at handover _____ kWh
	<b>Demand and yield forecasts</b>
	Expected electricity yield: _____ kWh/year
	Of which, expected direct consumption: _____ %
	<input type="checkbox"/> No forecasts have been made
<b>Feed-in management pursuant to EEG</b>	<b>Storage system in place (see storage passport)</b>
<input type="checkbox"/> Effective power reduction <input type="checkbox"/> Remote control capability	<input type="checkbox"/> no <input type="checkbox"/> yes : _____ kWh
<b>PV PASSPORT ISSUING BODY</b>	
This PV passport was issued by:	<a href="http://www.photovoltaik-anlagenpass.de">www.photovoltaik-anlagenpass.de</a>
Company _____	This seal confirms that the issuing company is registered with the BSW and ZVEH "PV Quality Group" (Qualitätsgemeinschaft Photovoltaik); see Internet site for benefits and list of installers.
Authorized person (first name, last name) _____	Company stamp
Street, house number _____	
Postal code, city _____	
The signee confirms that all information contained in this PV Passport and in Annexes 1 – 4 applies to the PV system that is described above and handed over to the buyer <sup>1)2)</sup>	
Date, signature of system builder/system vendor _____	

1) The PV Passport is only complete with Annexes (1) to (4)

2) While this PV Passport was compiled with greatest possible care, a guarantee for the attested characteristics cannot be given in terms of liability regardless of negligence.

**Annex 1: Components used**

Page \_\_\_\_ of \_\_\_\_ of Annex 1

**Photovoltaic modules**

Number of module types used: _____	
If multiple module types: Module type No. _____ (for multiple module types, please fill out a separate sheet for each type)	
<b>General information</b> (for details see attachment)	
_____	_____
Manufacturer (company name, headquarters)	Module type (name)
PV module capacity: _____ Wp	<input type="checkbox"/> CE compliance is fulfilled.

**Photovoltaic Inverters**

Number of inverters used: _____ (for more than three inverter types, please fill out a separate sheet)	
<b>General information</b> (for details see attachment)	
Inv. No. _____	
_____	_____
Manufacturer (company name, headquarters)	Inv. type (name)
Inv. No. _____	
_____	_____
Manufacturer (company name, headquarters)	Inv. type (name)
Inv. No. _____	
_____	_____
Manufacturer (company name, headquarters)	Inv. type (name)

### Photovoltaic Mounting System

General information	
Manufacturer (company name, headquarters)	
Type, description if applicable	
Type of fastening system (see attachment for details)	
<b>Mounting location:</b>	<input type="checkbox"/> flat roof <input type="checkbox"/> sloped roof (>5° slope) <input type="checkbox"/> facade <input type="checkbox"/> open space
<b>Design:</b>	<input type="checkbox"/> integrated <input type="checkbox"/> parallel <input type="checkbox"/> elevated (non-parallel) <input type="checkbox"/> tracking
<b>Fastening system:</b>	<input type="checkbox"/> weight-loading: <input type="checkbox"/> fastening provided <input type="checkbox"/> other
<input type="checkbox"/> estimated static friction coefficient: ____ <input type="checkbox"/> calculated static friction coefficient: ____	
<input type="checkbox"/> All relevant requirements pertaining to building authority regulations, such as state building code ( <i>Landesbauordnung</i> ), building rules lists ( <i>Bauregelliste</i> ) and technical building specifications ( <i>technische Baubestimmung</i> ) have been met.	
The dimensioning of the photovoltaic mounting system, including all fasteners and the applied load, has been carried out in accordance with relevant norms and standards, e.g. DIN EN 1991, as demonstrated by:	
<input type="checkbox"/> separate verification, issued by:	
<input type="checkbox"/> object-specific system calculation / type structural calculation, issued by:	
<input type="checkbox"/> general building authority approval:	
Roof hooks (if applicable)	
Manufacturer (company name, headquarters)	
Type, description if applicable	
<b>Roof hook installation:</b> <input type="checkbox"/> milled roof tile <input type="checkbox"/> pre-fab with pre-installed fastener <input type="checkbox"/> ventilation tiles used for cable channels	

**Annex 1: Components used**

Page \_\_\_\_ of \_\_\_\_ of Annex 1

**Cables / Power lines**

General information (for details see attachment)		
<b>PV string cable / power line</b>		
Manufacturer	Type	Cross-section
<b>PV main cable / power line (DC)</b>		
Manufacturer	Type	Cross-section
<b>Inverter supply cable / power line (AC)</b>		
Manufacturer	Type	Cross-section

**Feed-in Management / Communication**

General information (for details see attachment)
<input type="checkbox"/> effective power reduction pursuant to EEG: <input type="checkbox"/> 70% provision <input type="checkbox"/> other provision (e.g. KfW support measure): _____% Implementation takes place with: <input type="checkbox"/> permanent inverter settings <input type="checkbox"/> feed-in management system <input type="checkbox"/> other measures: _____ Type, manufacturer (company name, headquarters)
<input type="checkbox"/> communication of effective feed-in levels to network operator:

Yield protection, system security
The system has integrated function monitoring capability: <input type="checkbox"/> Yes <input type="checkbox"/> No If yes: <input type="checkbox"/> with a clearly perceptible alarm system <input type="checkbox"/> with remote monitoring capability
The following theft-control measures have been implemented: <input type="checkbox"/> theft protection of mounting system/modules through: _____ <input type="checkbox"/> theft protection of inverter through: _____ <input type="checkbox"/> other measures: _____

## Installation

General
<input type="checkbox"/> The installation of the PV system was carried out in accordance with recognized technical rules and standards.
<input type="checkbox"/> The PV system was built with minimal shadowing effect.
<input type="checkbox"/> A shading analysis was incorporated into the yield forecast (required given a notable degree of shading).
Structural information
<input type="checkbox"/> For roof-mounted systems, the load bearing capacity of the substructure has been assessed by (name):
<input type="checkbox"/> For roof-mounted system, the aging condition of the rooftop surface has been assessed by (name):
<input type="checkbox"/> The anchoring and load application was carried out in accordance with the manufacturer's calculatory proofs or the type structural calculations for the mounting structure as well as relevant mounting instructions.
<input type="checkbox"/> The fastening of the modules was carried out in accordance with the manufacturer's guidelines.
<input type="checkbox"/> Using alternative means (description, reason):
<input type="checkbox"/> Roof perforations were carried out in accordance with technical rules and standards.
<input type="checkbox"/> If roof hooks come into contact with roofing tiles or stones, approval has been given by the roofing tile/stone manufacturer.
Height of building: _____m    Wind load zone: _____    Snow load zone: _____
Edge distances: eave: _____m    Roof ridge: _____m    Gable: _____m
Fire safety measures
<input type="checkbox"/> Smoke and heat exhaustion systems are fully functional.
<input type="checkbox"/> Firewalls and fire compartments have been taken into consideration in accordance with fire protection regulations.
<input type="checkbox"/> Other measures:

**Annex 2: Information regarding planning and installation**

Page 2 of 2 of Annex 2

<b>Electrical safety, choice and installation of electrical equipment</b>	
<p>The system and the choice and installation of equipment was installed according to the general provisions of DIN VDE0100 and the specific provisions of VDE 0100-712 and VDE-AR-N 4105, and inspected according to the provisions of E DIN IEC 62446 (VDE 0126-23). Among others, the following specifications were met:</p>	
<input type="checkbox"/>	The PV system's cables and power lines were selected and installed in a way that makes them "earth fault and short circuit safe" in accordance with VDE 0100-520.
<input type="checkbox"/>	The installation of the inverter(s) with regard to max. input voltage and voltage at the maximum power point (MPP) was carried out in accordance with the manufacturer's guidelines.
<input type="checkbox"/>	The location of the installed inverter was chosen in accordance with the manufacturer's guidelines on heat dissipation and IP protection ratings.
<input type="checkbox"/>	The cables and power lines used in outside areas have sufficient UV and temperature resistance in accordance with manufacturer's guidelines for PV systems in outside areas.
<input type="checkbox"/>	The cables are attached to the frame, have no contact to the surface of the roof and are not routed over sharp edges. If possible, cables have been laid in shaded areas. The necessary strain relief has been ensured at all connection points.
<input type="checkbox"/>	The circuit breakers used in the direct-current circuit are sufficient according to the manufacturer's guidelines with regard to the direct-current suitability and load switching capacity.

<b>Lightning and voltage surge protection</b>			
<p><i>Note: A PV system does not necessarily require the installation of a lightning protection system, which can be required in compliance with state building regulations (Landesbauordnung – LBO) or according to the respective contractual situation (e.g. insurance policy).</i></p>		Yes	No
1.	Is a lightning protection system required for the building? (building law, risk assessment, VdS) <b>If no, continue with point 11. Retrofitting is recommended!</b>	<input type="checkbox"/>	<input type="checkbox"/>
2.	Does a test report exist for the lightning protection system?	<input type="checkbox"/>	<input type="checkbox"/>
3.	Was the outside lightning protection system adjusted accordingly?	<input type="checkbox"/>	<input type="checkbox"/>
4.	Have separation distances been calculated?	<input type="checkbox"/>	<input type="checkbox"/>
5.	Have separation distances been observed?	<input type="checkbox"/>	<input type="checkbox"/>
6.	Is the PV generator directly connected to the lightning protection system?	<input type="checkbox"/>	<input type="checkbox"/>
7.	Has lightning protection equipotential bonding been carried out?	<input type="checkbox"/>	<input type="checkbox"/>
8.	Are type 1 DC lightning arresters installed in proximity to the entry point to the building's string cable?	<input type="checkbox"/>	<input type="checkbox"/>
9.	Is a type 1 lightning arrester installed on the AC-side of the inverter?	<input type="checkbox"/>	<input type="checkbox"/>
10.	Is a type 1 lightning arrester installed at the feed conduit's building entry point?	<input type="checkbox"/>	<input type="checkbox"/>
11.	Is there a type 2 DC surge arrester installed in front of the inverter on the DC side?	<input type="checkbox"/>	<input type="checkbox"/>
12.	Is there a type 2 surge arrester installed in front of the inverter on the AC side?	<input type="checkbox"/>	<input type="checkbox"/>
13.	Has a type 1-2-3 combination arrester been installed at the feed conduit's building entry point?	<input type="checkbox"/>	<input type="checkbox"/>
14.	Has equipotential bonding been carried out for the mounting structure? Note: Separate lightning protection = min. 4 mm <sup>2</sup> (unprotected cable channels) Combined lightning protection = min. 16 mm <sup>2</sup>	<input type="checkbox"/>	<input type="checkbox"/>

**Annex 3: Test certificate / test reports****Test certificate**

pursuant to E DIN IEC 62446 (VDE 0126-23, draft), Attachment A

Annex	Inspector/installer
System owner (first name, last name)	Inspector (first name, last name)
Location street, house number (building/property)	Company
Location postal code, city	Street, house number
The test certificate is based on test reports for the inspection of the PV string in accordance with recommendations from VDE 0126-23, and on the AC side of the PV system in accordance with VDE 0100-600 (see following pages).	Postal code, city

**Construction, substructure, inspection and electrical testing**

I/we, the person(s) responsible for the testing of construction and substructure, inspection as well as electrical testing of the photovoltaic system, have undertaken inspection and testing of construction and substructure with the necessary expertise and diligence, and hereby confirm that I/we have carried out the work that I am/we are responsible for according to the best of our knowledge and expertise.

**Test results**

- No deficiencies were found
- The photovoltaic system conforms to the recognized standards of electrical engineering.

Comments:

**Test of construction:**

Place, date of test

Name and signature of inspector

**Testing of substructure:**

Place, date of test

Name and signature of inspector

**Inspection:**

Place, date of inspection

Name and signature of inspector

**Electrical testing of DC-side (see protocol)**

Place, date of test

Name and signature of inspector

The scope of liability that applies to the signee(s) is limited to the above-described activities.

**Annex 3: Test certificate / test reports**

**Test report construction, substructure, inspection**

in accordance with VDE 0126-23, Attachment B

Testing	
Test date: _____	Inspector: _____
Start of test: _____ am/pm, End: _____ am/pm	(first name, last name)
Electric circuits inspected (for large-scale systems and separate inspections, please use one sheet per inspection):	
<input type="checkbox"/> Total photovoltaic system <input type="checkbox"/> Following electric circuits: _____	

Construction and installation of the PV generator
<input type="checkbox"/> The direct-current system was constructed, chosen and installed in accordance with the general provisions of IEC 60364 and the specific provisions of IEC 60364-712.
<input type="checkbox"/> The direct-current components are designed for direct-current operations.
<input type="checkbox"/> The direct-current components are designed for maximum direct-current voltage and maximum possible fault current.
<input type="checkbox"/> Protection is ensured through the use of class II or equivalent insulation on the direct-current side.
<input type="checkbox"/> PV cables were chosen and installed so that the risk of earth fault and short circuits is reduced to a minimum (IEC 60364-7-712 sec. 522.8.1).
<input type="checkbox"/> The wiring system was chosen and installed in such a way that it will withstand the expected external forces such as wind, ice build-up, temperature and sun radiation (IEC 60364-7-712 sec. 522.8.3).
<input type="checkbox"/> Alternate-current and direct-current cables are physically separated from each other.
<input type="checkbox"/> This system does not have string fuses.
<input type="checkbox"/> If there are no string fuses: The dimensioning of the module reverse current ( $I_r$ ) is greater than the possible reverse current.
<input type="checkbox"/> If there are no string fuses: The string cables are installed in such a way that they can absorb the maximum amount of combined fault current from parallel branches.
<input type="checkbox"/> There are direct-current circuit breakers installed on the direct-current side of the inverter (IEC 60364-7-712 sec. 536.2.2).
PV system / surge protection / protection against electrical shock
<input type="checkbox"/> The inverter has a simple separation between alternate-current and direct-current side.
<input type="checkbox"/> If necessary, a fault current protection system is installed on the AC-side of the inverter, in accordance with a type B FI protection switch (IEC 60364-7-712 sec. 413.1.1.2).
<input type="checkbox"/> The surface area of all cable loops has been kept as small as possible (IEC 60364-7-712 sec. 54).
<input type="checkbox"/> The equipotential bonding connection conforms to local specifications.
<input type="checkbox"/> If protection/functional equipotential bonding system cables are installed, these are routed in parallel and in as close contact as possible to AC and DC cables.

**Annex 3: Test certificate / test reports**

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*Test report construction, substructure, inspection (cont'd)*

<b>Special considerations regarding alternate-current electric current of the PV system</b>
<input type="checkbox"/> On the alternate-current side, provisions are in place facilitating the separation of the inverter.
<input type="checkbox"/> The PV power line/cable (AC) must be connected to the supply side of the protective system for the automatic shut-down of power supply to current-using equipment through the designated protective system.
<input type="checkbox"/> The safety settings of the inverter are set in accordance with local specifications.
<b>Labeling and identification of PV system</b>
<input type="checkbox"/> All electric circuits, protective devices, switches and connection terminals are labeled accordingly.
<input type="checkbox"/> All direct-current junction boxes display a warning that the active components inside the box are supplied by a PV string and can still be live after disconnection from the PV inverter and from the public power supply.
<input type="checkbox"/> The alternate-current power main circuit breaker displays a clearly identifiable label.
<input type="checkbox"/> At the point of interconnection, there are warnings pertaining to the dual power supply.
<input type="checkbox"/> A schematic circuit diagram is displayed on site.
<input type="checkbox"/> An indicator sign in accordance with VDE-AR-E 2100-712 is displayed on site for emergency workers.
<input type="checkbox"/> A general overview is displayed for emergency workers.
<input type="checkbox"/> All symbols and labels are suitably and permanently fastened.
<b>General (mechanical) installation of PV system</b>
<input type="checkbox"/> The frames and materials used in the PV modules are appropriate to the respective location (proofs attached).
<input type="checkbox"/> The PV modules are, in accordance with manufacturer's guidelines, properly fastened and stable, and rooftop connection components are weather-resistant.

<b>Comments to all test reports</b>

**Annex 3: Test certificate / test reports**

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**Test report on electrical testing of PV system's direct-current side** (in accordance with VDE 0126-23, Attachment C)

Testing									
<b>Tested PV strings</b> (for large-scale systems and separate tests, please use multiple sheets):									
<input type="checkbox"/> Overall photovoltaic system									
<input type="checkbox"/> Following strings: _____									
Testing equipment: _____									
<b>Weather conditions</b>		<input type="checkbox"/> Sunny		<input type="checkbox"/> Partly cloudy		<input type="checkbox"/> Overcast		<input type="checkbox"/> Heavy cloud cover	
<b>String</b>		<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>
Brand/model of PV inverter									
Serial number of PV inverter									
PV generator	Module								
	Number								
String parameter according to data sheet	U <sub>oc</sub> (STC)								
	I <sub>sc</sub> (STC)								
String voltage surge protection device	Type								
	Rated input current (A)								
	DC rating (V)								
	Switching capacity (kA)								
Wiring	Type								
	Active conductor (mm <sup>2</sup> )								
	Grounding conductor (mm <sup>2</sup> )								
Testing of polarity and identification									
Insulating resistance of string	Test voltage (V)								
	Positive electrodes – earth (MΩ)								
	Negative electrodes – earth (MΩ)								
Measured values of string	U <sub>oc</sub> (V)								
	I <sub>sc</sub> (A)								
	U <sub>mpp</sub> (V) (if needed)								
	I <sub>mpp</sub> (A) (if needed)								
Mains power failure test (e.g. network and system protection)									
Conductivity of grounding conductor (if given) to a grounding system									
Conductivity of functional equipotential bonding conductor (if given) (<math>\leq 1 \Omega</math> demonstrated)									
Foundation earth	<input type="checkbox"/>	Equipotential bonding rail	<input type="checkbox"/>	Main grounding	<input type="checkbox"/>	PE rail in distributor	<input type="checkbox"/>	.....	<input type="checkbox"/>

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**Annex 3: Test certificate / test reports**

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**Test protocol of the PV system's direct-current side in accordance with VDE 0100-600**  
according to form 1/2007 ZVEH/Bundesfachverband Elektrotechnik

Testing													
Test date: _____						Inspector: _____							
Start of test: _____ am/pm, End: _____ am/pm						(first name, last name)							
<b>Description of work to be tested:</b>													
Testing according to: DIN VDE 0100-600 <input type="checkbox"/> DIN VDE 0105-100 <input type="checkbox"/> BGV A3 <input type="checkbox"/> .../..... BSV <input type="checkbox"/> E-Check <input type="checkbox"/>													
Network ..... / ..... V Network configuration: TN-C <input type="checkbox"/> TN-S <input type="checkbox"/> TN-C-S <input type="checkbox"/> TT <input type="checkbox"/> IT <input type="checkbox"/>													
Network operator: _____													
Inspect	OK	not OK		OK	not OK		OK	not OK		OK	not OK		
Choice of equipment	<input type="checkbox"/>	<input type="checkbox"/>	Labeling of electric circuit, equipment	<input type="checkbox"/>	<input type="checkbox"/>	Accessibility	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>		
Circuit breaker and switching devices	<input type="checkbox"/>	<input type="checkbox"/>	Labeling N- and PE-conductors	<input type="checkbox"/>	<input type="checkbox"/>	Main equipotential bonding	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>		
Fire-resistant sealings	<input type="checkbox"/>	<input type="checkbox"/>	Conductor connections	<input type="checkbox"/>	<input type="checkbox"/>	Additional local equipotential bonding	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>		
Building automation systems	<input type="checkbox"/>	<input type="checkbox"/>	Protection and monitoring equipment	<input type="checkbox"/>	<input type="checkbox"/>	Documentation, see additional sheets	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>		
Cables, power lines, power rails	<input type="checkbox"/>	<input type="checkbox"/>	Protection against direct contact	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>		
	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>		
<b>Test</b>													
Functional testing of system	<input type="checkbox"/>	<input type="checkbox"/>	Function of protection, safety and monitoring equipment	<input type="checkbox"/>	<input type="checkbox"/>	Right-handed rotary field of three-phase socket	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>		
FI circuit breaker (RCD)	<input type="checkbox"/>	<input type="checkbox"/>	Rotation direction of motors	<input type="checkbox"/>	<input type="checkbox"/>	Building automation systems	<input type="checkbox"/>	<input type="checkbox"/>		<input type="checkbox"/>	<input type="checkbox"/>		
<b>Measure Power circuit distributor No.:</b>													
Power circuit		Power lines/cables		Voltage surge protection device			R <sub>iso</sub> (MΩ)		Fault current protection device (RCD)				Error code
No.	Target name	Type	Conductor Number x diameter (mm <sup>2</sup> )	Type	I <sub>n</sub> (A)	Z <sub>v</sub> (Ω) <input type="checkbox"/> I <sub>v</sub> (A) <input type="checkbox"/>	without <input type="checkbox"/> with <input type="checkbox"/>	I <sub>n</sub> /type (A)	I <sub>Δn</sub> (mA)	I <sub>Δn</sub> (mA) (I <sub>Δn</sub> )	Period of measurement t <sub>A</sub> (ms)	U <sub>i</sub> ...V U <sub>max</sub> (V)	
			x										
			x										
			x										
			x										
			x										
			x										
Conductivity of grounding conductor 1 Ω <input type="checkbox"/>						Grounding resistance: R <sub>E</sub> ..... Ω							
Conductivity of equipotential bonding ( 1 Ω demonstrated)													
Foundation earth electrode	<input type="checkbox"/>	Main water line	<input type="checkbox"/>	Heating system	<input type="checkbox"/>	Computer system	<input type="checkbox"/>	Antenna system/BK	<input type="checkbox"/>		<input type="checkbox"/>		
Equipotential bonding rail	<input type="checkbox"/>	Main grounding conductor	<input type="checkbox"/>	Air conditioning	<input type="checkbox"/>	Telecommunications system	<input type="checkbox"/>	Building construction	<input type="checkbox"/>		<input type="checkbox"/>		
Water sub-meter	<input type="checkbox"/>	Interior gas line	<input type="checkbox"/>	Elevator system	<input type="checkbox"/>	Lightning protection system	<input type="checkbox"/>	.....	<input type="checkbox"/>		<input type="checkbox"/>		
Measuring equipment used in accordance with VDE .....		Manufacturer: _____ Type: _____		Manufacturer: _____ Type: _____		Manufacturer: _____ Type: _____							
Test result: <input type="checkbox"/> No deficiencies were found. <input type="checkbox"/> The following deficiencies were found: _____													
<input type="checkbox"/> The electric system conforms to the recognized standards of electrical engineering.													
Place, date _____						Signature _____							

**Annex 4: Overview of documents provided**

The operator was provided the following documents:

**A. Documents that must be provided:**

- A1: Electric circuit diagram, including string layout and list of equipment
- A2: (Rooftop) configuration plan with inverter positioning

For PV modules used

- A3: Technical data sheets
- A4: User information, assembly and instruction manual
- A5: List of serial numbers of all modules (e.g. flash list)
- A6: Warranty documentation
- A7: Copies of test certificates
- A8: Conformity declarations
- A9: Manufacturer's statement on normal combustibility

For inverters used:

- A10: Technical data sheets
- A11: User information, assembly and instruction manual
- A11: List of serial numbers of all inverters
- A13: Warranty documentation
- A14: Copies of test certificates
- A15: Conformity declarations

For all other components used:

- A16: Technical data sheets
- A17: User information
- A18: List of serial numbers
- A19: Warranty documentation
- A20: Copies of test certificates
- A21: Conformity declarations

For storage system used:

- A22: Technical data sheets
- A23: User information
- A24: List of serial numbers
- A25: Warranty documentation
- A26: Copies of test certificates
- A27: Conformity declarations

#### **Annex 4: Overview of documents provided**

For the mounting system used:

- A28: Requirements based on individual verification of structural strength or of system/type structural strength
- A29: General building authority approval, if necessary
- A30: Examination of structural strength of substructure
- A31: Mounting instructions of substructure components used
- A32: General building authority test certificate regarding the property of rigid roofing (only for integrated PV systems)

**B. Additional documents** (if applicable)

- B1: Calculation of yield forecast
- B2: Technical documentation of function monitoring system
- B3: Calculation of direct consumption rate
- B4: Calculation of static friction coefficient for ballasted roof systems

PV passport and Annexes (1) to (4) received:

\_\_\_\_\_  
*Date/signature of system operator*



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