Financial Modelling of PV Risks

Financial Modelling of Technical Risks in PV Projects

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Foreword

The photovoltaic (PV) sector has overall experienced a significant growth globally 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 standardization 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 with technical risks and sensitivity analyses are performed.

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 outcomes are best practices 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.

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 2017.

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

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Glossary & Abbreviations

AIFMD	Alternative Investment Fund Managers Directives
BM	Business model
CAPEX	Capital expenditures
CDF	Cumulative distribution function
CdTe	Cadmium telluride
CPN	Cost priority number
cts	Cents
DSCR	Debt service coverage ratio
DSRA	Debt service reserve account
EIOPA	European Insurance and Occupational Pensions Authority
EPC	Engineering, procurement and constructions
ESMA	European Securities Markets Agency
ESRB	European Systemic Risk Board
EU	European Union
EUR	Euro
EURIBOR	Euro Interbank Offered Rate (reference for interest rate)
FMEA	Failure mode and effects analysis
FiT	Feed-in tariff
GHI	Global horizontal irradiation
GPR	Guaranteed performance ratio
GW	Gigawatt
GWp	Gigawatt peak (size of PV installation)
IRR	Internal rate of return
kWh	Kilowatt hour
kWh/a	Kilowatt hour per year
kWh/m²/a	Kilowatt hour per square meter and year
kWp	Kilowatt peak

LCOE	Levelised cost of electricity
LCR	Liquidity coverage ratio
MCR	Minimum capital requirement
MW	Megawatt
MWp	Megawatt peak (size of PV installation)
n.a.	Not applicable
NPV	net present value
NREAP	National Renewable Energy Action Plan
NSFR	Net stable funding ratio
O&M	Operations and maintenance
OPEX	Operational expenditures
PID	Potential induced degradation (PV panel failure)
POA	Plane-of-array (irradiation)
PR	Performance ratio
PV	Photovoltaic
REC	Renewable energy certificate
SCR	Solvency capital requirement
TCO	Transparent conductive oxides
UCITSD	Undertakings for Collective Investment in Transferable Securities Directives
UV	Ultraviolet
WEEE	(European) Waste Electronics and Electrical Equipment

Executive Summary

Whilst writing these lines Europe is celebrating the milestone “100 GW of Solar Power Installed in Europe”. In the last decade grid-connected photovoltaic power has advanced from an absolute niche position to a central building block of future electricity generation. Costs of PV systems have fallen more than 70% since 2008 and levelised cost of electricity will continue decline supported by economies of scale and ongoing innovation.

Along with the increasing importance in Europe’s future energy mix the technical reliability and financial stability of PV investments has to match established standards in the utility industry. Hence, the Solar Bankability project aims to establish a common practice for professional risk assessment which will serve to reduce technical risks associated with investements in photovoltaic projects.

Since the start of the Solar Bankability project several reports have already been published. They provide an overview of technical risks of PV systems and introduce a systematic cost-based FMEA method to rank these risks using cost priority numbers (CPN). They describe suitable risk mitigation measures under different cost scenarios and their impact on the cost priority number. They analyse the concept of levelised cost of electricity (LCOE) and summarise technical assumptions and gaps influencing the calculation of lifecycle costs including CAPEX, OPEX and yield. All reports can be downloaded free of charge from the project website www.solarbankability.eu.

This report introduces in chapter one the cash flow model – and particularly the input and output parameters - as tool to measure the economic viability and profitability of long-term investments in PV projects. In chapter two, a detailed definition of total failure costs is provided and the specifications of a customised risk modelling tool which has been programmed especially for this modelling exercise is presented. Figure 1 presents the general architecture of the modelling tool.

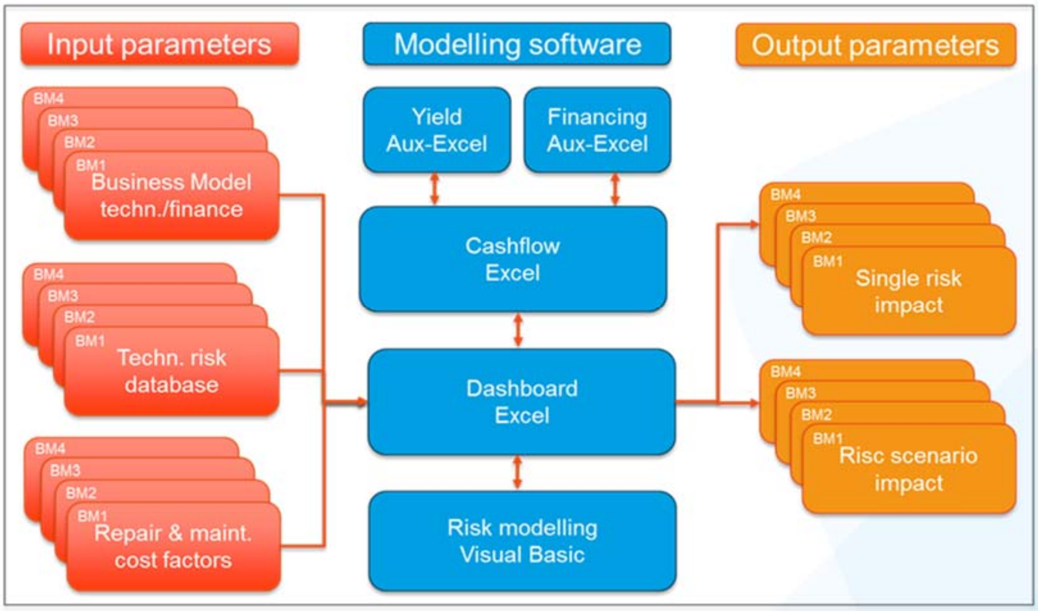


Figure 1: System architecture of risk modelling tool

Four representative business models are selected as basis for the modelling of technical risks. They cover different system sizes, PV technologies, geographic locations, climatic conditions and national incentive schemes. A summary of the four business models is shown in figure 2. Further PV business models can be easily integrated into the modelling software upon demand.

Figure 2: Selected business models

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

Based on the CPN risk priority list developed earlier in the project – Report on technical risks in PV project development and PV plant operation [8] – 10 to 12 single technical risks are identified per business model. Input parameters for a corresponding best and worst case are put together. For each business model a sample risk scenario consisting of up to four technical risks (from the 10 to 12 selected) is defined for the simulation of cumulative risks along the life cycle of a PV project.

Technical risks, once occurred turn into technical failures. These are distinguished according to the timing of their occurance into infant, mid-life and wear-out failures. The economic impact of failures is measured against year one revenues of a PV project and divided in five categories. Category 0 is normally covered by the regular O&M budget. Categories 1 and 2 are normally covered by a debt service reserve account. Categories 3 and 4 require the injection of additional equity capital, if not covered otherwise by guarantees, warranties or insurances. These are presented in figure 3.

In the risk modelling exercise for each of the four business models the impact of technical failures is analysed. For each failure the failure category, the impact on the internal rate of return (IRR) and a detailed break down of total failure costs in its sub-components is determined and the impact of the risk scenario on the cumulative cash flow of the PV project is measured.

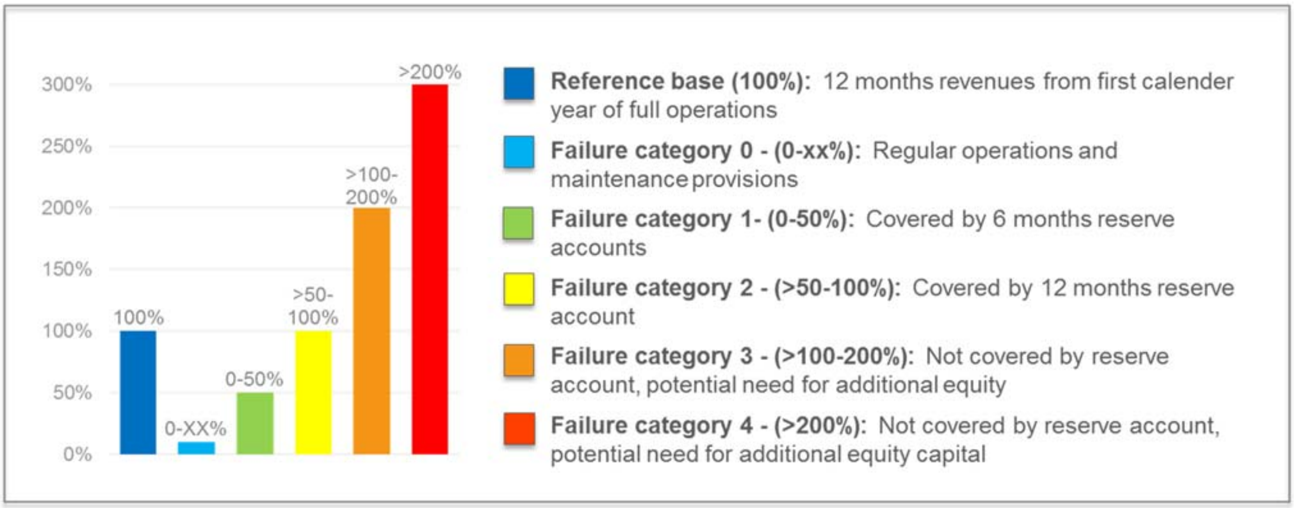


Figure 3: Definition of failure impact categories

A catalogue of suitable risk mitigation measures is introduced. For each business model the investor has to make an individual cost benefit analysis and define what budget he is prepared to invest in risk mititagion measures and how much of his base case profitability he is willing to “sacrifice” for the improved quality of the PV system and the enhanced stability of the cash flow model. For each businness model a customized risk management plan should be conceived which reflects the life time of the PV project, the bathtub curve of risk occurance and critical milestones. An example for a residential PV system is highlighted figure 4 below.

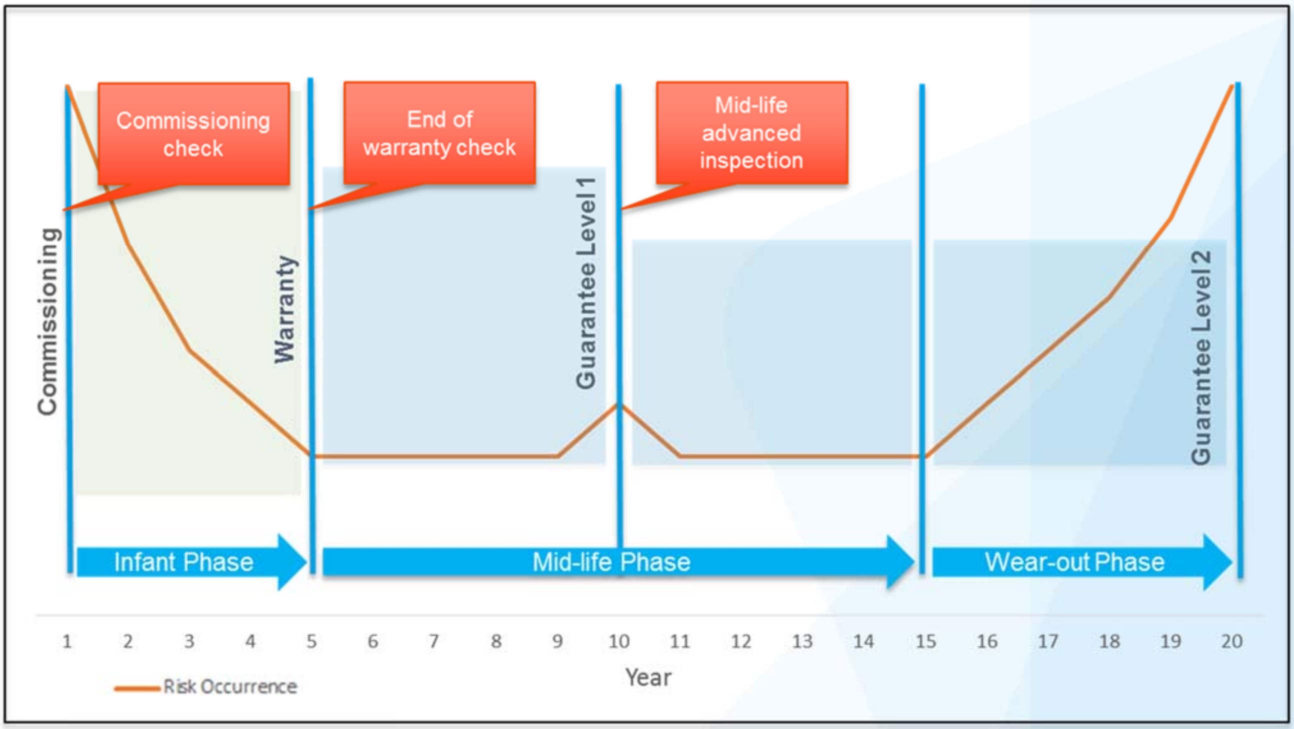


Figure 4: Example of minimum risk mitigation plan for residential PV system (BM 1)

Chapter five provides a short overview of new capital market regulations introduced after the financial crisis in 2008 and their impact on infrastructure investments in general and PV projects in particular. Under the Basel III framework for the banking industry PV projects don’t fall under the category of “high quality liquid assets” and therefore require higher liquidy reserves making PV financing less attractive and more costly. On the other hand under the Solvency II framework for the insurance industry, PV projects are considered as favorable infrastructure investements with somewhat reduced solvency capital requirements. With the Capital Markets Union an action plan is introduced by the European Union to channel additional capital investments from institutional investors such as insurances and pension funds to long-term infrastructure and sustainable projects. The new capital market regulations introduce new risk management and reporting requirements which lead to an increase in administrative costs. The findings of the project aim to provide a sound reference to guide the banking and insurance industry to enhance existing risk management systems and to build up their own inhouse team specialised in PV risk assessment or to engage the expertise of external professional rating services. Figure 5 illustrates the fundamentals of these new capital market regulations.

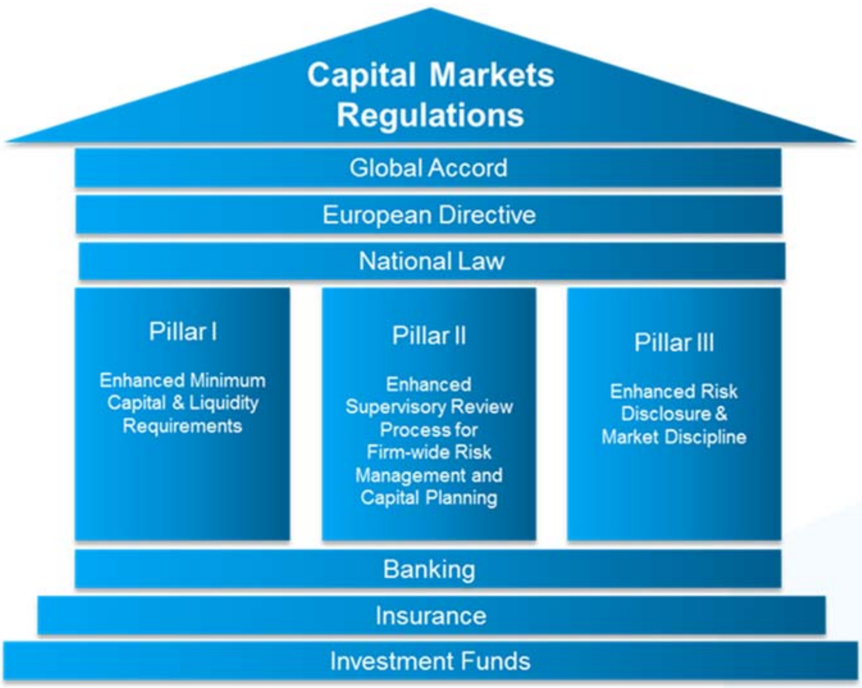


Figure 5: Three pillar model for new capital markets regulations

In the closing remarks the report summarises the top ten takeaways for PV stakeholders including policy makers, actors from the financial markets, plant owners, system installers and component manufacturers.

Table 1: Top 10 takeaways from the risk modelling exercise for PV stakeholders

1. PV investments are considered as qualified infrastructure investment. Compared with other asset classes PV projects offers a favourable risk profile. Under Solvency II the corresponding equity stress factor has been lowered accordingly.
2. New capital market regulations require a thorough due diligence and ongoing risk management procedures. Banks and insurances are requested to either implement a qualified inhouse risk rating or to take advantage of external professional rating services.
3. Most rating schemes for PV projects are compost of several risk categories. One of them are technical risks which represent up to 20% of the total rating scheme.
4. The impact of technical failures cannot be generalized. It depends on the individual framework conditions of the underlying PV business model , i.e. system size and design, geographic location, climate, technology, financing, taxation, jurisdiction and national policies.
5. The financial impact of technical failures beyond those already reflected by regular O&M provisions can be classified in four failure categories. Only categories 1 and 2 are covered by regular operations and maintenance provisions and reserve accounts. Failures in category 3 and 4 are more common in smaller than in larger PV systems. The financial impact of failures often depends to a large extend on high spare parts costs for modules and inverters,high downtime costs due to long detection and repair/substituion times and higher yield losses especially during the summer season.
6. PV investments require an enhanced risk awareness and active risk management. Since the financial crisis in 2008 the profitability of PV systems has decreased along the decline of overall financial market returns. Increased competition and cost pressure in the PV industry are threatening quality standards. Manufacturer and EPC insolvencies have made product warranties and performance guarantees become void.
7. A professional risk management plan should become integral part for each PV investment. The budget for risk assessment and mitigation measures should be adjusted to size and investment volume of the PV project. Mitigation measures should reflect the “bathtub” like curve of risk occurance and important milestones of system design, commisioning, end of warranty and guarantee periods. Ongoing monitoring and maintenance checks will help to minimize the occurance of failures.

8. Manufacturers and EPC should use the risk assessment and modelling methodology and the risk data base developed under the Solar Bankability project and incorporate the lessons learnt into their component and system design. Rather than exchanging entire components, smart repair should become market standard i.e. to exchange defective module junction box diodes or inverter circuit boards. A PV system design based on. micro or string inverters sometimes might be less downtime prone than one based on central inverters.
9. Banks and insurers should use the risk assessment and modelling methodology and the risk data base developed under the Solar Bankability project to optimize and adjust i.e. required debt service reserve accounts or to adjust insurance premiums according to the risk rating and age of the PV system
10. To enhance the effectiveness of government tender schemes for large PV projects regulators should consider to include also non-monetary qualification requirements beyond the price-only criteria. A professional risk management plan to ensure the financial viability and technical reliability of the PV system should be incorporated. A quality monitoring program should accompany the tendering process. It should cover the project realization rate and a technical quality and performance check before the end of the PV system warranty period.

1. Introduction

1.1. Financial Modelling of PV Projects

The economic viability and profitability of long-term PV project investments is most commonly determined by use of a cash flow model, which helps to calculate the internal rate of return, the break-even point and the cumulative cash flow of the project. All cash in- and out-flows during the entire lifetime of the project are considered and discounted over time. Due to this discounting method cash flows have a larger impact at the beginning rather than at the end of the project.

The generic structure of a cash flow model reflects several input and output parameters at project start, during operation and at decommissioning.

1.1.2. Input Parameters

Year-0 Parameters

Plant parameters: Location and type of PV system (roof-top/ground mounted, etc.), nominal capacity, annual yield, annual degradation, start of operation, project duration.

CAPEX: Encompass total investment costs including project development, land purchase, EPC, due diligence and financing.

Financing: Equity capital, debt capital and conditions of credit including term, interest rate and redemption.

Legal/tax: Legal and ownership structure with respective income tax and depreciation rates.

Electricity tariff/business model: The electricity tariff will depend on the type of, the nominal capacity and the start of operation of the PV-system as well as the underlying business model i.e. feed-in tariff, net-metering, self-consumption or power purchase agreement.

Parameters during Operation

Revenues: Revenues depend on the electrical yield of the PV-system, its annual degradation and the respective electricity tariffs under a FiT, net metering or power purchase scheme. In case of self-consumption the relevant demand curve and the electricity tariff for self-consumption have also to be considered.

OPEX: Encompass all expenses to operate and maintain the PV plant during the operational years, including costs for operations and maintenance, land lease, debt service, insurance and tax.

Reserves: Different reserves are included to reflect seasonal fluctuations and single events. Most common is the repair and maintenance reserve to cover ongoing repair and maintenance including the replacement of inverters at the end of service life. In case of debt financing, banks will ask for a debt service reserve account to ensure complete and ontime payments. A decomissioning reserve can accumulate the costs of dismantling the PV-system at the end of its service life.

Parameters at Decomissioning

CAPEX: Potential costs of decommissioning of the PV system at the end of its regular service life or proceeds from a sale of PV system in case of a potential repowering of the PV-system.

Figures 6 and 7 show an overview of CAPEX and OPEX items found in surveyed financial models. A more detailed description of these expenditures is provided in the report "Review and Gap Analyses of Technical Assumptions in PV Electricity Cost" [1]. The comparison of CAPEX respectively OPEX figures for particular projects turns out to be difficult, because the cost elements accounted under CAPEX and OPEX are not standardized and can vary from project to project.

Figure 6: List of CAPEX items found in surveyed financial models of ground mounted PV projects in FR and UK

Figure 7: List of OPEX items in 18 surveyed financial models of ground mounted PV projects in FR, UK, DE, IT

1.1.2. Output Parameters

The cash flow model provides a number of output parameters, which allow to rate the economic viability and profitability of a PV project.

Cash flow/cumulative cash flow: Cash flow is the net amount of cash moving in and out of the PV project. The cumulative cash flow indicates the sum of all cash flows over the course of the PV project.

Liquidity: Reflects the cash flow plus reserves, excluding depreciation. It indicates if an investor is able to pay out dividends or might need to inject fresh capital.

Payback time/break even: Indicates the point in time when cumulative revenues equal cumulative costs, that means from this point onwards profits begin to accumulate and the project becomes financially viable.

Internal rate of return (IRR)/net present value (NPV): The IRR is the discount rate at which the net present value of all cash flows from the project equals zero. The higher the IRR the more attractive it is for the investor to engage in the PV project. A distinction is being made between the equity IRR based on 100% equity financing and the project IRR based on partial debt financing.

Debt Service Coverage Ratio (DSCR): The DSCR is a measure of the cash flow available to pay current debt obligations. The ratio states the net operating income as a muliple of debt obligations due within one year.

1.1.3. Cash Flow Modelling Tools

The structure of PV cash flow modelling tools available in the market nowadays, is quite similar. The format of the modelling tool however is not standardised and will vary depending on the underlying PV business model.

Ready-to-use modelling tools can be found in the internet either as online or download version. Dedicated cash flow modelling tools are available as simple FiT-based versions like PVCalc [2] or more sophisticated versions, which can simulate different PV business models like pv@now [3] or PV Power Invest [4]. Combined modelling tools include cash flow and yield calculation. Well known combined tools on a commercial basis are PV*SOL® [5] or PVsyst [6]. Inverter manufacturers often offer free-of-charge combined tools such as SMA Sunny Design [7].

The above tools do not provide any guarantee for the modelling results. For large utility scale PV projects showing a high degree of complexity with regard to the legal, tax and financing structure, it is most common to develop a dedicated PV project modelling tool, which subsequently can be certified by an external auditor to meet the professional risk management requirements of institutional investors.

However, until today there are no commercial risk modelling tools available in the market which allow for the analysis of technical failures and their economic impact over the entire lifecycle of PV systems.

2. Risk Modelling Tool

The cash flow model assesses the financial performance of a PV system under regular operating conditions. However throughout the life cycle of a PV system additional risks are likely to occur. The Solar Bankability project has developed a systematic methodology to identify technical risks, to structure them in a risk matrix, to quantify their economic impact with a CPN and to prioritize them. A CPN list has been determined on the basis of more than 700 PV plants with a total capacity of around 420 MWp across all market segments [8]. In contrast to this rather statistical methodology the risk modelling approach tries to simulate the impact of technical risks on selected PV business models with a clearly defined system technology at a given geographic location. A dedicated modelling tool has been developed within the Solar Bankability project to cover these parameters.

2.1. Definition of Total Failure Costs

For the calculation of the economic impact of technical risks on the cash flow model, the total failure costs C_{fail} can be split in two parts, the downtime costs C_{down} and the fixing costs C_{fix}.

$$C_{fail} = C_{down} + C_{fix} \tag{1}$$

Downtime costs

The downtime costs reflect impact from a reduced power production or a complete outage of the PV system and the associated loss in revenues from the missed sale of electricity or missed self-consumption (e.g. for PV installed on buildings). Downtime costs are influenced by the occurence over time and the severity of the failure.

The occurence can be broken down in several time elements. The time to detect t_{det} desribes the duration from the start of the PV system fault till detection. The time to repair/substitute $t_{rep/sub}$ describes the duration to repair or substitute components including procurement and transportation lead times. The time to fix t_{fix} describes the duration to fix the failure till restart of normal system operations.

The severity can be described by a performance loss factor PL, a multiplier m and the yield loss of the affected component. PL represents the fraction of performance loss caused by the failure, where $PL = 1$ indicates a total loss.The multiplier m reflects the circumstance that a failure can cause performance losses at a higher component level, i.e. a single module failure can affect the performance of an entire module array. Depending on the affected component the yield loss can be broken down from inverter, to string and eventually to module level. Therefore any yield loss of a component can be expressed as a multiple of the yield of a single module Y_{mod}.

The performance loss factor PL is composed of two elements PL_1 and PL_2, where PL_1 covers the time frame t_{det} and $t_{rep/sub}$ and PL_2 covers t_{fix}. PL_2 equals 1 if fixing of the PV system requires a complete shut down of the PV system, i.e. for safety reasons.

Thus the downtime costs can be calculated by the formula:

$$C_{down} = ((t_{det} + t_{rep/sub}) \times m \times PL_1 + t_{fix} \times m \times PL_2) \times Y_{mod} \times P_{el} \qquad (2)$$

where

- C_{down} = downtime costs [EUR]
- t_{det} = time to detect [days]
- $t_{rep/sub}$ = time to repair/substitute - including transpotation time [days]
- t_{fix} = time to fix [days]
- m = muliplier at higher component level [-]
- PL_1 = performance loss during t_{det} and $t_{rep/sub}$ [-]
- PL_2 = performance loss during t_{fix} [-]
- Y_{mod} = module yield = PV system yield/number of modules [kWh]
- P_{el} = electricity price under FiT, REC or PPA scheme [EUR/kWh]

For PV systems with battery storage and self-consumption there are two elements of downtime costs. Different electricity prices have to be reflected for the feed-in share and the self-consumption share of solar electricity. The formula for downtime costs needs to be adjusted accordingly.

$$C_{down} = C_{down,fit} + C_{down,sc} \qquad (3)$$

Fixing costs

The fixing costs can be broken down in detection, repair/substitution, transportation and labour costs.

The detection costs C_{det} cover various cost elements including visual inspection, field test (i.e. hot spot), laboratory (i.e. electroluminescence) and third party expert opinions. Costs for a monitoring system usually are accounted for under regular O&M costs.

The repair/substituion costs $C_{rep/sub}$ cover costs for the repair of defect components or the complete subtitution of irreparable components.

The transportation costs C_{trans} cover the tranportation of components and other miscellaneous costs such as security costs (i.e. the protection of a PV site) and safety costs (i.e. the scaffolding at a roof-top PV system).

The labour costs C_{lab} cover all personnel related costs during time to fix t_{fix} including hourly wages, travel costs and other expenses.

$$C_{fix} = C_{det} + C_{rep/sub} + C_{trans} + C_{lab} \qquad (4)$$

where

- C_{det} = detection costs [EUR]
- $C_{rep/sub}$ = repair/substitution costs [EUR]
- C_{trans} = transportation costs [EUR]
- C_{lab} = labour costs [EUR]

The CPN methodology introduced in the Solar Bankability report Techical Risks in PV Projects [8] uses a statistically driven top-down cost approach, where the overall C_{det}, $C_{rep/sub}$, C_{trans} and C_{lab} are considered to be directly proportional to the number of failures n_{fail}.

This approach can be most suitable for large utility scale PV systems. However, under certain circumstances it has some drawbacks. The detection costs for animal bites can be rather high and are not directly proportional to the number of defect components. Repair and substitution costs of components depend on the degree of damage and often require further differentiation. Some components can be repaired whilst others must be substituted. Transportation costs depend very much on the batch size and vary whether pallets or containers are used. For small residential PV systems, the labour cost for the replacement of a single component can be less than the actual travelling expenses.

For the modelling of technical risks basically the same cost calculation method as for the CPN can be applied. However, for the modelling, a more detailed bottom-up approach is preferred, based on the experience gained during the handling of more than 3,500 PV insurance claims. This allows to determine more accurately the fixing costs for both large and small PV systems.

2.2. Specifications for Risk Modelling Tool

There are no commercial risk modelling tools available in the market which allow the analysis of technical failures and their economic impact over the lifecycle of PV systems. Therefore a customized tool had to be developed for the Solar Bankability project as shown in figure 8.

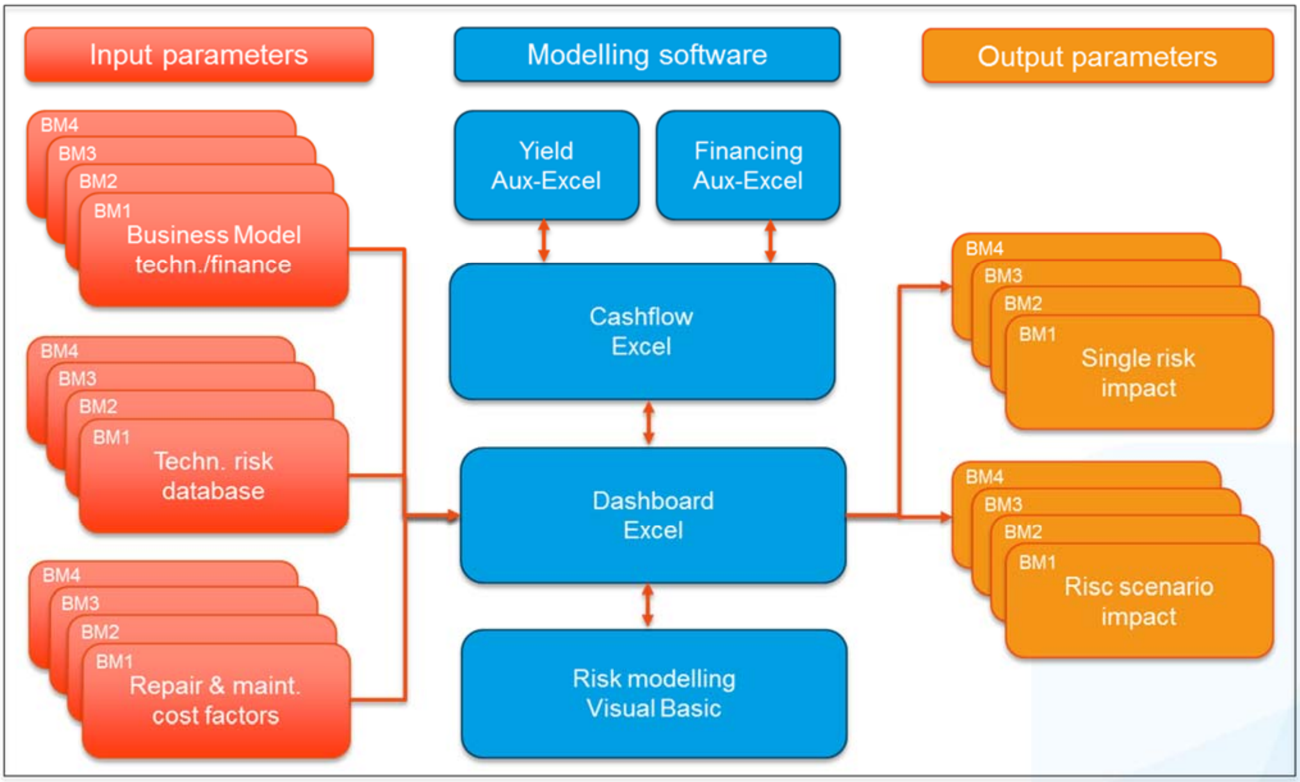


Figure 8: System architecture of risk modelling tool

The system architecture of the risk modelling software uses a proven spreadsheet based cash flow model as backbone. Auxiliary spreadsheets are dedicated to the yield and debt financing calculation. The cash flow model is linked with a risk modelling module programmed in Visual Basic. The entire modelling software is controlled from a dashboard which is embedded in the spreadsheet-based tool.

A business model selector in the dashboard enables the selection of the technical and financial data of individual business models and the corresponding risk database. The user can select between one to four technical risks from the risk database for the modelling of single risks or risk scenarios. Every failure, it´s starting date and duration can be manually adjusted to simulate the impact at different stages of the PV project lifecycle. The option to combine several failures with different attributes enables the user to simulate various risk scenarios along the entire lifecycle.

Upon completion of the input parameters a starter button initiates the dynamic calculation of technical risks in the risk modelling tool. The associated failure costs C_{fail} are split into fixing and downtime costs. The fixing costs C_{fix} are added to the OPEX in the cashflow. The downtime costs C_{down} are deducted from the solar energy yield. The results of the calculation are written into a report sheet for each business model. The sheet contains both tables and graphs to summarize the impact of single risks and entire risk scenarios.

The risk modelling tool is based on a 40 year time frame. Many feed-in tariff schemes reach up to 20 years.Today’s physical lifetime of PV systems ranges between 20 and 30 years. In the future more and more PV systems will be repowered at reasonable costs and their theoretical lifetime will be extended up to 40 years. Thus the tool enables investors like insurances and penion funds to cover their longterm investment horizon.

The yield of PV systems is subject to sizeable seasonal changes due to the fluctuation of solar irradiation. Hence the impact of technical risks varies considerable with the date of risk occurance. In order to reflect this circumstance, quarterly instead of yearly time increments have been implemented in the risk modelling tool.

To limit the complexity and shorten the run time of the risk modelling software, some compromises in the system design turned out to be necessary:

- The accuracy of input and output parameters is limited to two digits.
- In the modelling of performance lossses only PL_1 was considered for the total duration of failure while PL_2 was neglected. Usually total downtime costs are more heavily influenced by the time to detect and repair/substite than by the time to fix the failure. In most cases downtime costs during the time to fix are limited to the fraction of affected components.

Prior to the risk modelling exercise, the individual modules of the risk modelling tool have been thoroughly tested. The cash flow module in the spreadsheet-based tool was tested with pv@now as reference. The risk modelling module in Visual Basic was reviewed by an independent software expert. For individual technical risks the output of the modelling tool was compared with offline manual calculations. Through these measures, it was secured that the single modules of the modelling tool are working accurately and also display correct results, both for long (> 360 days) and short failure durations (< 2 days). The next step was to align all these proven calculation modules over a timeline and integrate them into a Visual Basic code. The timeline had to reflect a freely selectable starting date and the quaterly seasonality of solar irradidation. To evaluate the results which are generated by the different modules, a complex write-out topology had to be generated.

The variability of PV system technologies and business models, and the compilation of input parameters requires a deep understanding of PV system design, CAPEX and OPEX, and repair and maintenance practices. Given the overall complexity of the risk modelling tool, only a trained and experienced user can operate the tool in a meaningful manner.

3. Risk Modelling Input

Modelling the economic impact of technical risks on the cash flow of PV projects requires the selection of the underlying business models, selection of associated technical risks, likely risk scenarios and the underlying cost assumptions.

3.1. PV Business Model Selection

The Solar Bankability report PV Business Model Country Snapshots [9] introduces eight generic PV business models and provides a snapshot of seven national PV markets and their current business model roll-out situation, including Germany, Italy, France, Spain, United Kingdom (UK), Romania and the Netherlands.

At the end of this report four business models were selected for the financial modelling of technical risks. In the selection process various criteria were considered such as PV system size, module and inverter technology, ground and roof-top mounting, solar electricity feed-in and self-consumption, geographic location and climatic conditions.

1) Business model 1: Residential rooftop PV system with crystalline silicon modules located in central Europe (base case),
2) Business model 2: Residential rooftop PV system with crystalline silicon modules and battery storage located in central Europe,
3) Business model 3: Utility scale ground mounted PV system with crystalline silicon modules located in central Europe,
4) Business model 4: Utility scale ground mounted PV system with thin film CdTe modules located in southern Europe.

Based on these descriptions four existing PV systems were identified with the support of the consortium partners and members from the Project Advisory Board, which is a cluster of mainly investors/bankers with long experience in solar financing accompanied with project developers and EPCs and component manufacturers. For each business model technical and financial parameters were obtained from the system owners and are summarized in Appendix A. Solar irradiation and yield data were obtained from the PVGIS photovoltaic calculator Europe [10]. Table 2 gives an overview over the particular business models. More details are provided in Appendix A.

Table 2: Business model overview

	BM 1	BM 2	BM 3	BM 4
Location	Palatinate Germany	Bavaria Germany	Nottinghamshire UK	South Tyrol Italy
System type	residential, roof-top	residential, roof-top	utility, ground mounted	utility, ground mounted
Nominal capacity (kWp)	5.64	5.20	7619.00	662.6
Module	Yingli 235P	Aleo S79 L260	Q CELLS Q.Pro-G3 260	First Solar FS277
Inverter	SMA SB5000TL	SMA SB2.5 1VL-40	SMA SC800CP-XT	SMA SMC8000TL
Battery	n.a.	IBC Solstore Li 6.5	n.a.	n.a.
CAPEX (EUR)	confidential	confidential	confidential	confidential
OPEX (EUR/a)	confidential	confidential	confidential	confidential
Global tilted irradiadiance (kWh/m²/a)	1229	1260	1195	1675
Annual Production (kWh/a)	5558	5267	7355057	966016
Start of operation	January 2011	January 2015	January 2011	July 2010
Feed-in tariff	0.2874	0.1231	0.1560	0.3600
Self-cons. tariff (EUR/kWh)	n.a.	0.2792	n.a.	n.a.

Since the focus of the financial modelling exercise lies on the assessment of the economic impact of technical risks, certain compromises were made on purpose to simplify the implementation of the cash flow model and to enhance the transparency and comparability of results.

Details of the CAPEX and OPEX figures were not disclosed by the system owners. Therefore the figures had to be entered on an aggregate rather than on a breakdown level. The PVGIS calculator provides rather basic irradiation and yield data. No special effort was made to further optimise these values.

In a discussion with the Project Advisory Board, it was decided to base the cash flow modelling for all business models on a 100% equity financing structure. Thus the economic impact of technical risks remains more objective and comparable and is not influenced by different financial leverage ratios which are subject to the individual risk/return preferences of individual investors.

3.2. Technical Risk Selection

In the Solar Bankability report “Technical Risks in PV Projects” [8], technical risks were identified and categorised for components and phases of the value chain of a PV project. The technical risks were broadly divided into risks to which one can assign an uncertainty to the initial yield assessment and risks to which one can assign a CPN. While failures arising from technical risks belonging to the first group have an impact on the overall uncertainty of the initial yield assessment, failures with a CPN have a direct impact on the annual cost of running a PV plant caused by economic losses due to downtime and component repair or substitution.

For the purpose of this report the focus lies on the assessment of the economic impact of technical risks occurring during the operations and maintenance phase (O&M) of a PV project. Risk associated with the uncertainty of the initial yield assessment have been extensively analysed in the Solar Bankability report “Review and Gap Analysis of Technical Assumptions in PV Electricity Cost” [1].

The selection of technical risks during the O&M phase is based on the failure database described in the report “Technical Risks in PV Projects” [4]. This database was developed with a portfolio of more than 700 PV plants, 420 MWp, ~2,000,000 modules, ~12,000 inverters, etc. for a total of ~2.4 million components. With the help of filter criteria the database can be sorted into different sub-databases.

In a multistep selection process the database is filtered for a set of top 10 general technical risks which apply to all four business models and can be compared across these business models.

Step 1: Sub-database 1 contains top 10 technical risks from all affected plants with a maximum assumed detection time for technical risks of 365 days. This selection step focuses on maximum total loss as sum of fixing costs (C_{fix}) and downtime costs (C_{down}).

Step 2: Sub-database 2 contains top 10 technical risks from all affected plants where the failures are fixed immediately and downtime costs are minimal. This selection step focuses on maximum fixing costs (C_{fix})

Step 3: Sub-database 3 contains top 10 technical risks from all plants with a maximum assumed detection time for technical risks of 365 days. This selection step focuses primarily on the risks with the highest occurance and secondarily on the the maximum total loss as sum of fixing costs (C_{fix}) and downtime costs (C_{down}).

Step 4: Sub-database 4 contains top 10 technical risks from all plants where the failures are fixed immediately. This selection step focuses primarily on the risks with the highest occurence and secondarily on the maximum fixing costs (C_{fix}).

From each sub-database those risks which contain an evident numerical error, which are not described in detail in Appendix 2 [8], or which are not applicable to all four PV business models, are eliminated.

For identification purposes each technical risk from the top 10 list receives a four digit risk number. The first digit indicates the business model. The last digit differentiates between the base and worst case, where 0 stands for the base case and 1 stands for the worst case. The following table 3 gives a short description of the top 10 generical risks.

Table 3: Selection of top 10 generic technical risks

Risk Number[3)]	Component	Name	Description	BM 1	BM 2	BM 3	BM 4
xx00 xx01	C-Si module	Potential induced degradation (PID)	When the charged atoms are driven, from voltage potential and leakage currents, between the semiconductor material and other components of the module e.g. frame, glass etc. Low fill factor measurement might indicate PID phenomenon.	x	x	x	1)
xx00 xx01	CdTe module	Low power/ TCO corrosion	Performance loss specific to CdTe thinfilm modules due to accelerated initial or corrosion induced degradation of the active layer.				x
xx10 xx11	Module	Failure of bypass diode/ junction box	May cause heating of the cells, or reduce the generated energy. The defective diode can be detected by opening the junction box or by measuring the open circuit voltage of the module.	x	x	x	x

Risk Number[3)]	Component	Name	Description	BM 1	BM 2	BM 3	BM 4
xx20 xx21	C-Si Module	Hotspot	Overheating of cells etc. can cause burn marks. Temperature difference between neighbour cells should not be over 30°C. Infrared cameras can be used for imaging the defects of the modules. Hotspots can also be identified by visual inspection from the rear side of the module.	x	x	x	2)
xx30 xx31	Module	Theft or vandalism	Significant reduction in the energy production	x	x	x	x
xx40 xx41	Inverter	Fan failure and overheating	May cause the temperature derating and reduce the production. Following the inverters' error message, appropriate measures must be taken immediately.	x	x	x	x
xx50 xx51	Inverter	Lightning strike	European standards require the protection of metallic structures and electronic devices against lightning strike. A lightning protection can prevent the plant from being stopped for several weeks and substitution of expensive components.	x	x	x	x
xx60 xx61	Mounting	Mismatch of module clamp	May cause frame damage, glass breakage or unsufficient fixation of module.	x	x	x	x
xx70 xx71	Cable	UV aging of string cable	Happens when the cable is exposed to UV radiation. This phenomenon can be reduced by protecting the cables from direct exposure to sunlight.	x	x	x	x

Risk Number3)	Component	Name	Description	BM 1	BM 2	BM 3	BM 4
xx80 xx81	Cable	Wrong/ absent cable connection	Different types (brands) of connectors are used often in practice. Besides the fact that they may not fit correctly, the durability of the connection is not certain. Thus, it is highly recommended that only connectors of the same type are installed.	x	x	x	x
xx90 xx91	Cable	Cabling damaged by rodents	This may lead to a performance reduction and even a safety risk. The repair costs depend on the design of the plant.	x	x	x	x

1) PID is not applicable to CdTe thin film modules
2) Hot spots are only typical for crystalline silicon modules
3) Base case: Last digit = 0 / Worst case: Last digit = 1

This list of top 10 general technical risks - shown in table 4 - is then amended by a selection of one or two risk specific to the technical design or the climatic conditions of each of the four business models.

Table 4: Selection of business model specific technical risks

Risk number	Component	Name	Description	BM 1	BM 2	BM 3	BM 4
1100 1101	Module	Glass breakage by hail	Glass breakage during operation caused by hail	x			
1110 1111	Module	Soiling of module	Performance loss due to soiling caused, amongst others, by pollution, bird droppings, and accu-mulation of dust and/or pollen. Its impact is strongly site dependent.	x			

Risk number	Component	Name	Description	BM 1	BM 2	BM 3	BM 4
2100 2101	Battery	Failure of battery	Performance loss of battery caused, amongst others, by premature aging of battery cells		x		
2110 2111	Inverter	Failure of battery inverter	Performance loss caused by overheating or complete destruction by grid or lighting surcharge		x		
3100 3101	Inverter	Flooding of inverter	Partial performance loss or complete destruction of inverters caused by flooding			x	
3110 3111	Module	Soiling of module	Performance loss due to soiling caused, amongst others, by pollution, bird droppings, and accumulation of dust and/or pollen. Its impact is strongly site dependent.			x	
4100 4101	Module	Glass breakage, frameless module	Glass breakage of frameless CdTe modules caused, amongst others, by mishandling, thermal stress, snow load				x

For each business model a database with a complete list of the selected technical risks is provided in Appendix B.

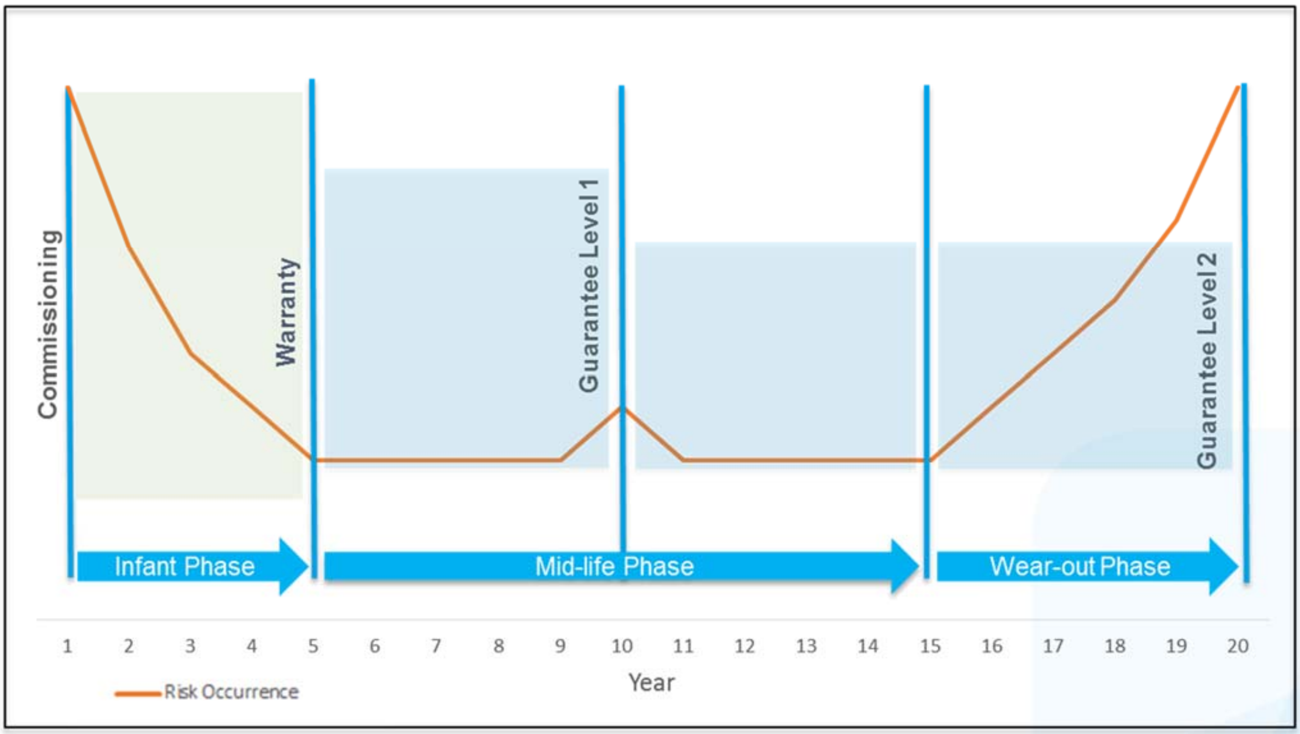
3.3. Technical Risk Scenario Selection

A PV project will be exposed to several technical risks throughout its operational phase. According to the occurrance of technical risks three categories of failure can be distinguished.

- **Infant failure:** Occurs during the initial run-in phase of the PV system, normally this is during the first two years of operations and should be covered by warranties from EPC or component manufacturers.
- **Mid-life failure:** Occurs in the middle of the project life cycle. Some of them might be covered by manufacturer guarantees like the module performance guarantee.
- **Wear-out failure:** Usually occurs during the end of the project life cycle. However for inverters the regular wear-out usually takes already place after 10 to 15 years.

The occurrence of technical risks - as shown in figure 9 - often follows a trough function with a higher occurence in the infant and wear-out phase and a somewhat lower occurance during the mid-life phase with a small interim peak at the end of inverter lifetime. More details about the lifetime of inverters can be found in the Solar Bankability report “Technical risks in PV projects” [8].

Figure 9: Schematic trough function of technical risk occurrence



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

In the technical risks scenarios a likely combination of four technical risks has been selected for each business model. The scenarios contain a mix of base case and worst case, and infant, mid-life and wear-out phase risks. Independent of the project phase are risks with an external cause such as theft or lightning, which can occur along the entire project lifecycle.

The following risk scenarios contain just a sample combination of risks. Under real operations conditions a multitude of combinations is theoretically possible for each business model.

Table 5: Selection of business model risk scenarios

Risk scenario - BM 1 *(start of operations: Jan 01, 2011)*

Risk	Risk number	Risk name	Start Date	Case	Phase
Risk 1	1061	Mismatch of module clamps	01.01.2011	Worst	Infant
Risk 2 1)	1111	Failure of bypass diode and juction box	01.03.2021	Worst	Mid-life
Risk 3	1041	Fan failure and overheating	01.08.2018	Worst	Mid-life
Risk 4 2)	1100	Module breakage by hail	01.08.2026	Best	Wear-out

Risk scenario - BM 2 *(start of operations: Jan 01, 2015)*

Risk	Risk number	Risk name	Start Date	Case	Phase
Risk 1	2000	Potential induced degradation (PID)	01.01.2015	Best	Infant
Risk 2 2)	2031	Vandalism of modules	01.02.2017	Worst	Infant
Risk 3 1)	2111	Failure of battery inververter	01.03.2023	Worst	Mid-life
Risk 4	2071	UV aging of string cables	01.07.2030	Worst	Wear-out

Risk scenario - BM 3 *(start of operations: Jan 01, 2011)*

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

Risk scenario - BM 4 *(start of operations: Jul 01, 2010)*

Risk	Risk number	Risk name	Start Date	Case	Phase
Risk 1	4001	Low power/TCO corrosion of module	01.07.2010	Worst	Infant
Risk 2 1)	4101	Glass breakage of module, frameless	01.01.2011	Worst	Infant
Risk 3 2)	4031	Theft of modules	01.02.2015	Worst	Mid-life
Risk 4	4081	Wrong/Absent cables connection	01.07.2025	Worst	Wear-out

1) Business model specific risk, i.e. due to system design/technology, geographic/climatic conditions

2) External cause independent from project phase

3.4. Repair and Maintenance Cost Assumptions

Repair and maintenance costs are subject to a considerable variance. Therefore the assumptions have to be based on best estimates backed by the experience of ACCELIOS Solar from handling of more than 3,500 insurance claims throughout Europe. All costs have been converted to Euro including business model 3 from the UK. The exchange rate was determined on June 01, 2016, prior to the BREXIT decision.

For PV systems without spare parts inventory the costs of spare parts are often considerably higher than OEM parts, since the same type of modules and inverters is no longer produced or the manufacturer has gone out of business. If parts with the same specification are no longer available, a redesign of module strings or the inverter configuration might become necessary. Due to economies of scale spare part prices for utility PV systems tend to be lower than for residential PV systems. As there are no established secondary markets in the PV industry the future price development for spare parts is hard to predict. Therefore fixed spare part prices are considered throughout the risk modelling exercise.

Labour rates can be split in three qualification levels. The highest rates apply especially for failure detection by PV experts and central inverter repair by OEM technicians. Sometimes safety regulations require the presence of two persons, i.e. for residential roof-top systems or for central inverter repair. Despite the fact that labour rates can vary significantly across countries for simplicity reasons the the labour rates were assumed to be identical in the risk modelling exercise.

Unit costs for the replacement include the time for disassembly and reassembly of components. Residential roof-top PV systems tend to be more complex and time consuming than large utility PV systems. Unit costs are hard to estimate and can vary with individual site conditions.

Travel, transportation and set-up costs can add a considerable amount to the total failure fixing costs, especially if the site of the PV system is far away, several trips are involved, safety scaffolding, cranes or forklift trucks have to be rented.

Table 6: Repair and maintenance cost assumptions

	Unit	BM 1	BM 2	BM 3[1)]	BM 4
Spare parts					
Module	EUR/unit	200.00	260.00	187.20	64.90
Inverter	EUR/unit	1325.00	980.00	62472.00	960.00
Inverter 10 year replacement/overhaul	EUR/unit	650.00	475.00	24000.00	960.00
Inverter fan	EUR/unit	n.a.	n.a.	2779.20	n.a.
Module clamp	EUR/unit	3.00	3.00	2.40	2.40
DC string cable	EUR/m	12.70	12.70	34.80	21.00
Cable connector (MC4)	EUR/unit	3.00	3.00	2.40	2.40
Battery inverter	EUR/unit	n.a.	1025.20	n.a.	n.a.
Battery	EUR/unit	n.a.	7226.90	n.a.	n.a.

1) Exchange rate GBP/EUR = 1.27807 (June 1, 2016)

	Unit	BM 1	BM 2	BM 3[1)]	BM 4
Lobor units					
Replacement of module	h/unit	0.50	0.50	0.25	0.25
Replacement of inverter	h/unit	1.00	1.00	10.00	0.75
Replacement of inverter fan	h/unit	n.a.	n.a.	5.00	n.a.
Replacement of module clamp	h/unit	0.10	0.10	0.03	0.03
Replacement of string cable + connector	h/unit	2.00	2.00	1.00	1.00
Replacement of cable connector	h/unit	0.50	0.50	0.25	0.25
Module cleaning	h/unit	0.10	0.10	0.01	0.01
Replacement of battery inverter	h/unit	n.a.	1.00	n.a.	n.a.
Replacement of battery	h/unit	n.a.	2.00	n.a.	n.a.
Labor costs					
O&M junior technician	EUR/h	40.00	40.00	40.00	40.00
O&M senior technician	EUR/h	60.00	60.00	60.00	60.00
OEM engineer/technical expert	EUR/h	100.00	100.00	100.00	100.00
Cleaning (including equipment)	EUR/h	50.00	n.a.	50.00	n.a.
Travel costs					
Kilometer flat (€/km)	EUR/km	0.50	0.50	0.50	0.50
Single travel distance O&M	km	20.00	20.00	100.00	100.00
Single travel distance OEM/Expert	km	250.00	250.00	250.00	250.00
Car costs O&M - return trip	EUR	20.00	20.00	100.00	100.00
Car costs OEM/expert - return trip	EUR	250.00	250.00	250.00	250.00
Travel time O&M - return trip	h	0.50	0.50	2.00	2.00
Travel time OEM/expert - return trip	h	5.00	5.00	5.00	5.00
Daily meal allowance	EUR/day	40.00	40.00	40.00	40.00
Hotel	EUR/night	n.a.	n.a.	80.00	80.00
Transport/set-up costs					
Transportaion module pallet	EUR/pallet	375.00	375.00	300.00	300.00
Transportation module containter	EUR/cont.	n.a.	n.a.	1800.00	1800.00
C-Si modules per container	units/cont.	700.00	700.00	700.00	n.a.
CdTe modules per container	units/cont.	n.a.	n.a.	n.a.	1800.00
Transportation inverter	EUR/part	375.00	375.00	960.00	300.00
Transportation inverter fan	EUR/part	n.a.	n.a.	100.00	n.a.
Rent crane/forklift truck	EUR/day	600.00	600.00	480.00	480.00
GSE registration fee	EUR/part	n.a.	n.a.	n.a.	800.00
Safety Scaffold	EUR// Ab.	700.00	700.00	n.a.	n.a.

1) Exchange rate GBP/EUR = 1.27807 (June 1, 2016)

3.5. Risk Modelling Input Factors

Based on the selection of risks and the repair and maintenance cost assumptions a dedicated table with risk modelling input factors has been prepaired for each of the four business models (see Appendix B).

The assumptions for the residential and utility scale PV systems can be summarized as follows in table 7:

Table 7: Assumptions for risk modelling input factors

Business models 1 and 2 refer to residential PV systems without monitoring. The base case describes an attentive owner, a low failure detection time, and only one of two module strings affected by a failure with low severity. The worst case describes a careless owner, a long failure detection time, and both module strings affected by a failure with high severity. For both cases the set-up and repair time are kept as short as possible.
Business models 3 and 4 refer to utility scale ground mounted PV systems. The base case describes a PV system equipped with simple monitoring, only a minor number of modules and inverters affected by a failure with low severity. The worst case describes a PV system without monitoring, a major number of inverters and modules affected by a failure with high severity. For both cases the set-up and repair time vary to a great extent due to different lead times and number of defective components.
In the modelling of performance lossses only PL_1 was considered for the total duration of failure while PL_2 was neglected. Usually total downtime costs are more heavily influenced by the time to detect and repair/substite than by the time to fix the failure. In most cases downtime costs during the time to fix are limited to the fraction of affected components.

A risk database containing all input factors for the risk modelling exercise for each business model is provided in Appendix B.

4. Financial Modelling of Technical Risks

4.1. Assessment of Risk Impact

In the risk modelling section both single technical risks and combined risk scenarios are analysed with respect of their financial impact on the base case of the underlying business model. The base case reflects the budgeted performance of the PV system under normal operating conditions and regular aging of components, i.e. module degradation or exchange of inverters after approximately 10 years. In the context of risk modelling the term failure is used for risks after their actual occurence.

As explained in section 1.1.2 the profitability of a business model can be assessed with a cash flow model on the basis of the internal rate of return IRR or the cumulative cash flow. Both measures are dependent on the boundary conditions of each business model, which depend on the start date, design, size, geographic, legal, fiscal, and financial framework of the PV system. A higher IRR or a higher cumultative cash flow tend to either reflect a higher risk/return ratio or a better buffer against the impact of risk. In line with financial market conditions and the increasing maturity of the PV market, the profitability of PV business models has decreased in recent years.

Whether a business model is financially viable depends very much on the individual preferences of an investor. Professional investors are often predominantly profitability driven. Purely financial investors tend to focus on maximum profit, whilst strategic investors like utilities might be prepared to compromise profitability against the renewable energy share in their overall energy portfolio. Retail investors show mixed investment motivations; especially residential house owners often pursue environmental and self-reliance motives beyond or besides pure profitability.

Given the above reasons a direct financial comparison of business models tends to be misleading as shown in the figures below, where i.e. business model 1 shows the highest IRR due to favorable feed-in tariff, CAPEX, OPEX and business model shows the highest cumulative cash flow due to the large nominal capacity of the project.

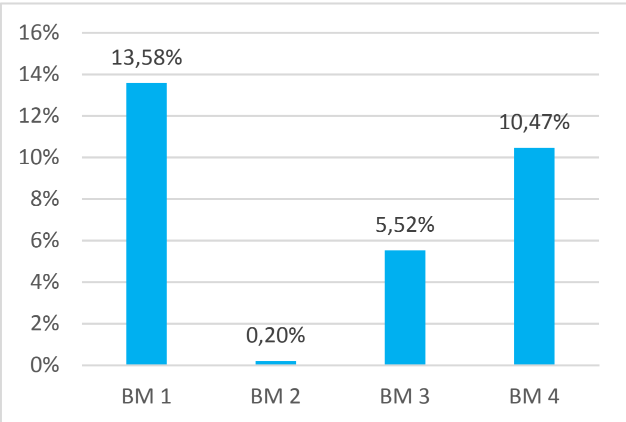


Figure 10: IRR comparison (base case)

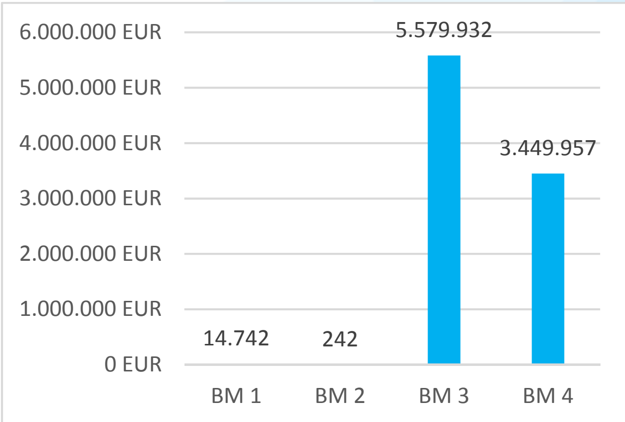


Figure 11: Cumulative CF comparison (base case)

A reserve account is often included in the cash flow model to buffer unanticipated business model risks. The size of the reserve account varies with the individual stability requirements of the investor or the financing bank. The size of the reserve account is measured as a fraction of the 12 months revenues in the first year of PV system operations. Banks usually ask for a debt service reserve account (DSRA) of 3-, 6- or up to 12-month revenues. Along these lines five distinct failure categories are introducedin figure 12 to describe the financial impact in terms of relative revenue losses.

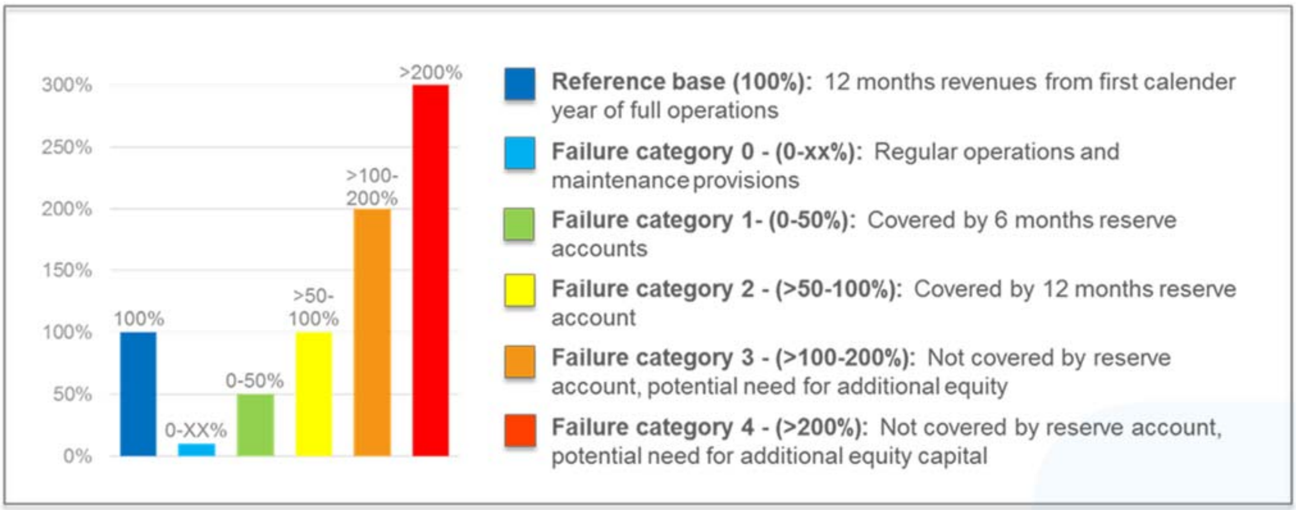


Figure 12: Definition of failure categories

The following figures 13 through 16 provide an overview of the failure distribution for the four business models split by best and worst case:

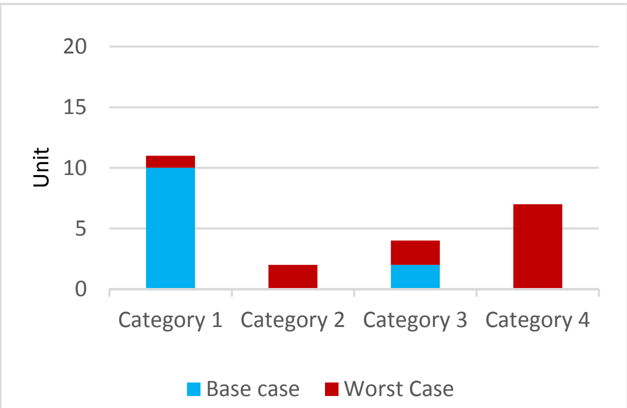


Figure 13: Failure category overview – BM 1

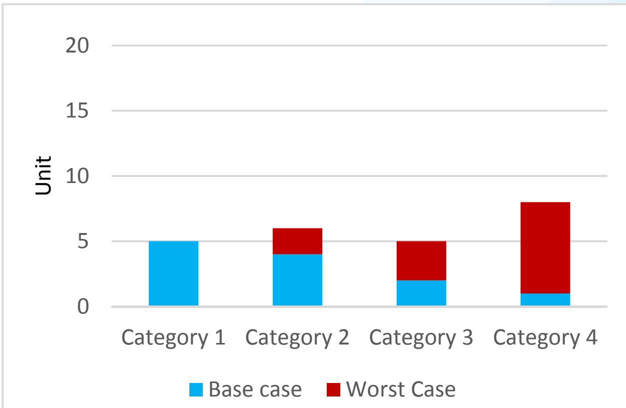


Figure 14: Failure category overview – BM 2

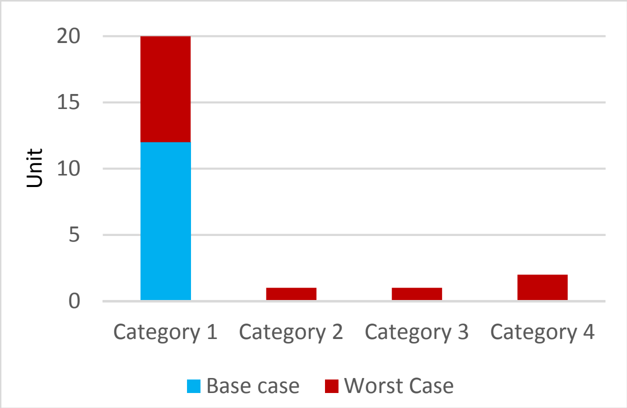


Figure 15: Failure category overview – BM 3

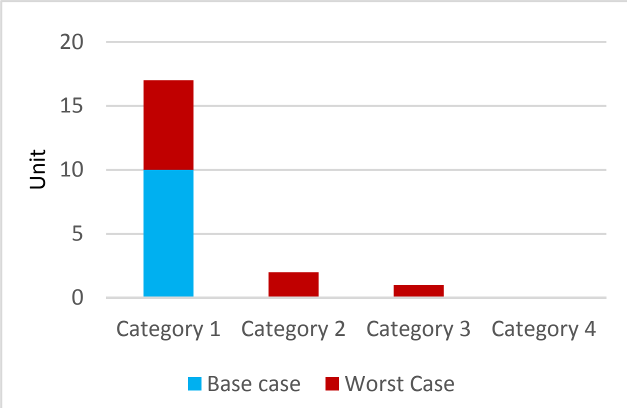


Figure 16: Failure category overview – BM 4

The residential sized business models 1 and 2 are most affected by the impact of technical failures, while the utility sized business models 3 and 4 turn out to be more robust. Business model 2 with 54% of all failures in categories 3 and 4 is the least robust, whereas business model 4 with just 13% of all failures in categories 3 and 4 is least impacted.

Residential PV systems are more vulnerable to failures, due to higher labour and spare parts costs and prolonged downtime costs due to in many cases missing monitoring systems. For utility scale PV systems a failure often affects only a fraction of the total solar electricity production. Online monitoring in combination with a service and maintenance contract lead to reduced downtime costs. With respect to labour costs and spare parts utility scale PV systems often can take advantage of additional economies of scale.

4.2. Impact of Technical Risks on Business Model 1

Business model 1 represents a residential roof-top PV system with a nominal capacity of 5,64 kWp located in central Germany. The system consists of a single string inverter and two strings with a total of 24 crystalline silicon modules. The system was commissioned in January 2011. The owner is a private investor interested in financial returns based on the 20 year feed-in tariff scheme.

4.2.1. Modelling of Single Technical Risks

Table 8 lists twelve single technical risks, each with a best case and worst case version covered by

Table 8: List of technical risks of BM1

the modelling exercise.

Table 8: List of technical risks of BM1

Risk number	Name of risk	Case
1000	PID = Potential Induced degradation	Best
1001	PID = Potential Induced degradation	Worst
1010	Failure of bypass diode and juction box	Best
1011	Failure of bypass diode and juction box	Worst
1020	Hotspot of modules	Best
1021	Hotspot of modules	Worst
1030	Theft/ vandalism of modules	Best
1031	Theft/ vandalism of modules	Worst
1040	Fan failure and overheating	Best
1041	Fan failure and overheating	Worst
1050	Lightning strike of inverter	Best
1051	Lightning strike of inverter	Worst
1060	Mismatch of module clamps	Best
1061	Mismatch of module clamps	Worst
1070	UV aging of string cables	Best
1071	UV aging of string cables	Worst
1080	Wrong/Absent cables connection	Best
1081	Wrong/Absent cables connection	Worst
1090	Cabling damaged by rodents	Best
1091	Cabling damaged by rodents	Worst
1100	Module breakage by hail	Best
1101	Module breakage by hail	Worst
1110	Soiling of modules	Best
1111	Soiling of modules	Worst

For 10 of the best case failures the economic impact remains in category 1 with only two best case failures fall in category 3. The impact of worst case failures is spread across all failure categories, two of them in category 3 and seven in category 4. The highest economic impact is caused by module with up to 510% followed by inverters with up to 207% of relative revenue losses (see figure 17).

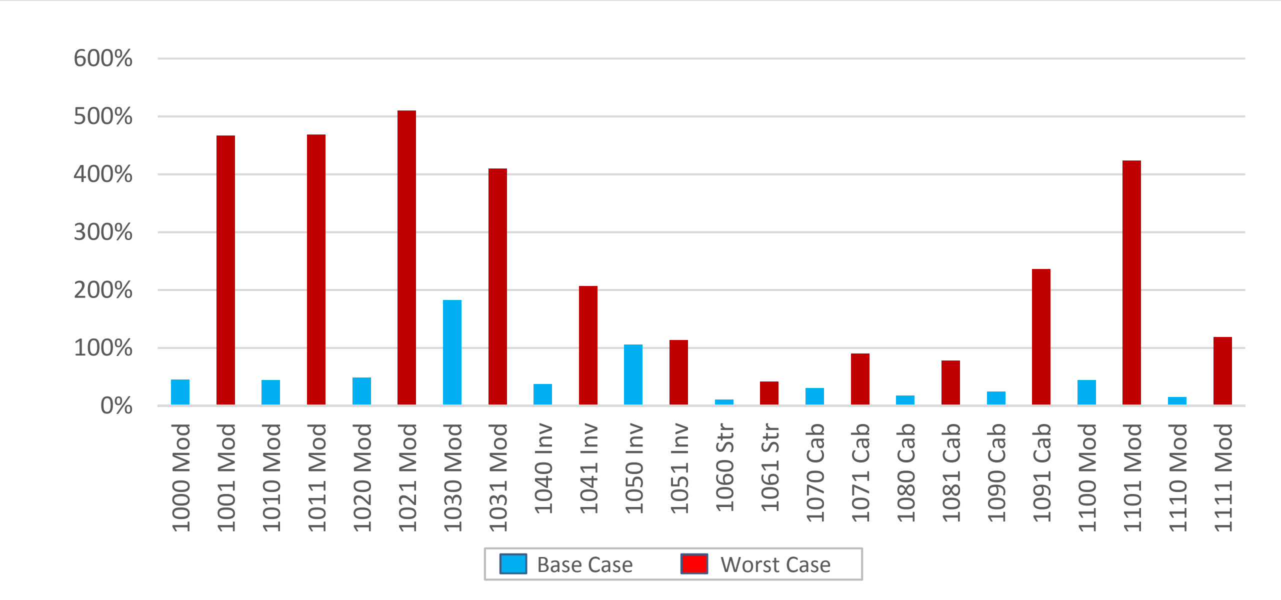


Figure 17: Relative revenue loss by failure of BM 1

The distribution of failure costs varies by type and nature of failure (see figure 18).

- **Repair and substitution costs ($C_{rep/sub}$):** These costs represent more than 50% for failures 1000, 1001, 1010, 1011, 1020, 1021, 1030, 1031, 1050, 1051, 1100 and 1051. Since OEM parts often are no longer available spare parts have to be purchased at higher costs from the secondary market. Modules with an outdated power rating require replacement by current module types with a higher rating.
- **Detection and fixing costs (C_{det} + C_{fix}):** Labour costs have a dominating influence on failures 1060, 1061, 1070, 1080, 1090 and 1110. For safety reasons often two people have to be involved in roof-top repair works and one technician has to secure the other.
- **Transportation costs (C_{trans}):** This cost category comprises both transportation and safety costs. The cost influence is usually minor, however more significant for utility sized systems, where full pallets or containers are used. Often a crane has to be rented to hoist tools and spare parts on the roof. For extended roof top repair works the installation of a safety net or scaffold is mandatory.
- **Downtime costs (C_{down}):** Solar electricity losses have a dominating influence on failures 1041, 1071, 1081 and 1111. They are especially high for failures with a long detection time because relative performance losses are relatively low and do not lead to an immediate outage of the PV system.

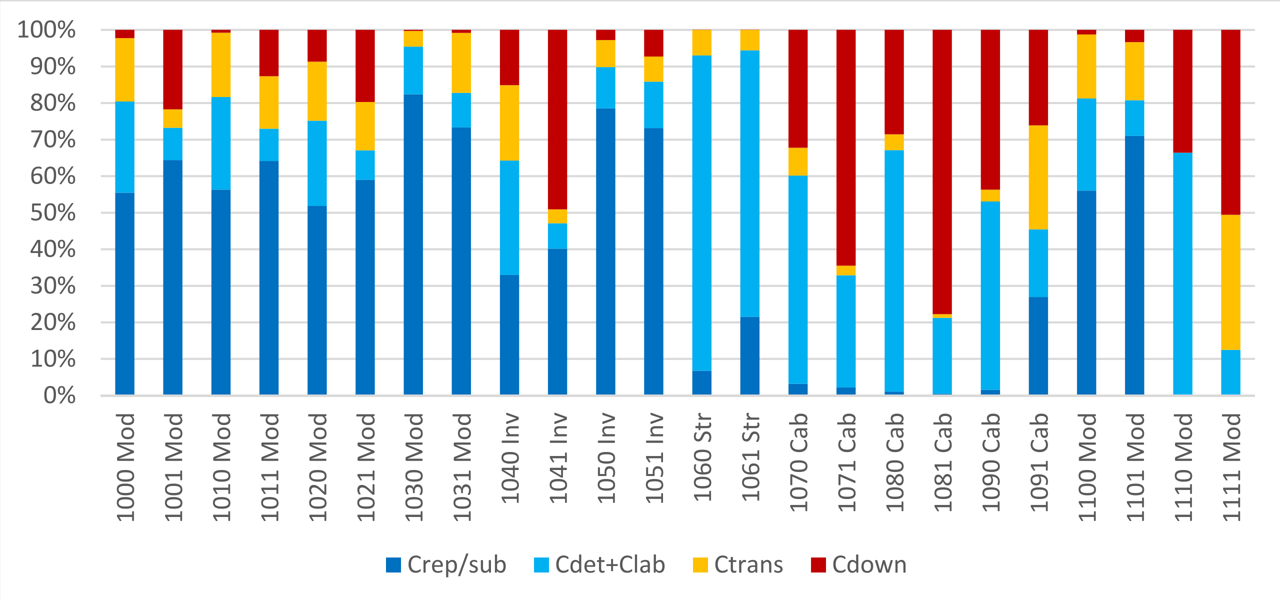


Figure 18: Distribution of failure costs by risk of BM 1

Most relevant for purely financial investors is the impact of failures on the IRR of the PV system. The impact depends on the amount of total fixing costs and the timing of failure occurrence. Among the selected failures PID of module (1001) has the largest impact. The base case project IRR gets reduced from 13.58% to 4.68%. With respect to the timing of the failure occurrence, seasonality between winter and summer season and the positioning at the beginning or end of the project life cycle can have a significant influences on the project IRR (see figure 19).

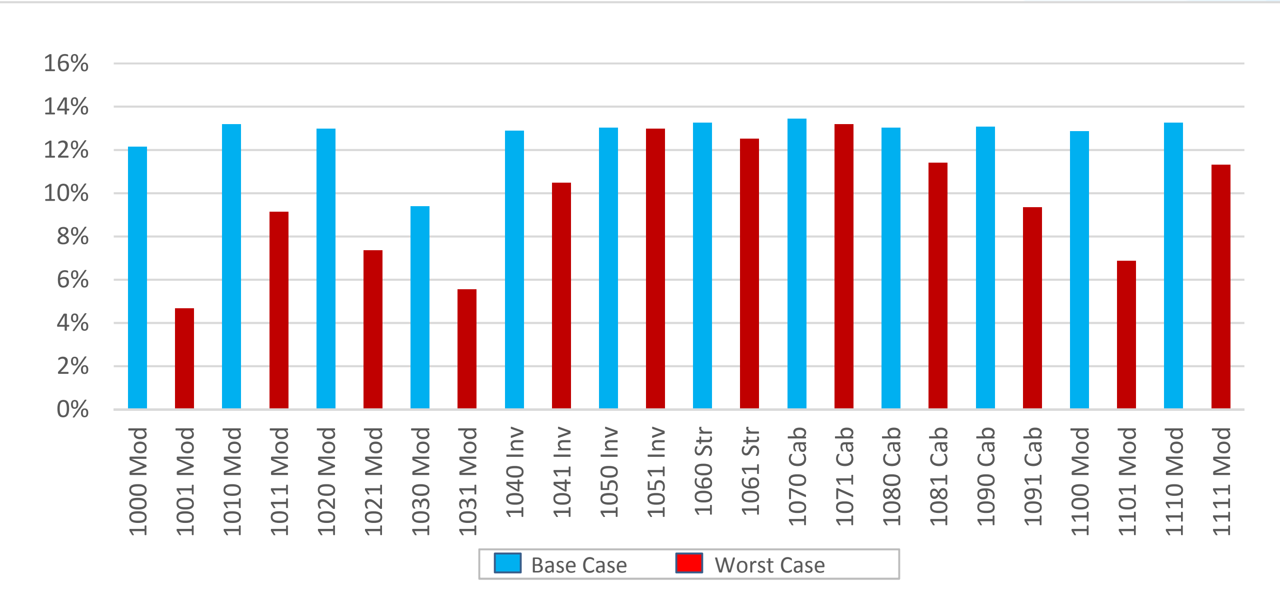


Figure 19: Impact of failure on project IRR of BM 1

4.2.2. Modelling of Technical Risk Scenario

In section 3.3 the following four risks were introduced for the risk scenario modelling of business model 1, listed in table 9.

Table 9: Risk scenario of BM 1

Risk	Risk number	Risk name	Start Date	Case	Phase
Risk 1	1061	Mismatch of module clamps	01.01.2011	Worst	Infant
Risk 2	1111	Failure of bypass diode and junction box	01.03.2021	Worst	Mid-life
Risk 3	1041	Fan failure and overheating	01.08.2018	Worst	Mid-life
Risk 4	1100	Module breakage by hail	01.08.2026	Best	Wear-out

- **1061 Mismatch of module clamps:** The installer has used wrong module clamps not in line with the module installation manual. The failure is detected at the end of the EPC warranty period during an inspection of the PV system. All module clamps have to be replaced. The failure falls in category 1. The total fixing costs are relatively low, with little spare part and labour costs and no solar electricity losses. The owner can try to claim the failure costs from his EPC.
- **1111 Soiling of modules:** The PV system is located in a rural area and dust is accumulating over time on the surface of modules. Despite a 30% performance loss the owner only became aware of the failure two years from its start. Cleaning of modules is carried out by a professional cleaning company. During the roof-top work a scaffold is used for safety reasons. The failure falls in category 3. Total fixing costs are dominated by the performance losses. The scaffold adds a considerable cost amount. Failure costs will have to be borne by the owner.
- **1041 Fan failure and overheating:** The inverter is installed in a location with poor ventilation leading to frequent overheating and shutdown of the inverter especially during the summer season. In the second summer the failure is detected after a complete breakdown of the inverter fan. The more than seven year old inverter is replaced by a new one and installed in a location with proper ventilation. The failure falls in risk 4. Total fixing costs are dominated by performance losses and spare part costs. The owner can try to claim the failure costs from his EPC.
- **1100 Module breakage by hail:** A summer thunderstorm with hail causes a complete destruction of two out of the twenty four modules of the PV system. The failure is detected immediately. The reordering of spare modules from the secondary market takes two weeks. During this time one out of two strings looses twenty percent of its performance. The failure falls in category 1. Total fixing costs are dominated by spare part costs. The owner can claim the failure costs from his insurer.

The failure costs associated with the risk scenario amount to a total of 435% in relative revenue losses. Fixing costs represent 61% and downtime costs 39% (see table 10).

Table 10: Risk scenario results of BM 1

No	Risk	Name of risk	Start date of failure	Total fixing costs of risk C_{fix}	Total down time costs of risk C_{down}	Total failure costs of risk C_{fail}	IRR (incl failure)	Cumulative cash flow (incl failure)	Relative revenue Loss C_{fail}/R_{12}	Failure category
1	1061	Mismatch of module clamps	01.01.2011	670	0	670	12.52%	14.072	42%	1
2	1111	Soiling of modules	01.03.2021	936	926	1.862	12.59%	12.880	117%	3
3	1041	Fan failure and overheating	01.08.2018	1.680	1.605	3.285	11.09%	11.457	206%	4
4	1100	Module breakage by hail	01.08.2026	705	259	964	18.40%	125	60%	2
Total - non discounted static values				3.991	2.962	6.953	8.22%	7.789	435%	4

The risk scenario negatively impacts the financial performance of the PV system. The base case project IRR of 13.58% is reduced to 8.22% and the cumulative cash flow over the project lifetime is cut down from EUR 14,742 to EUR 7,789 (see figure 20).

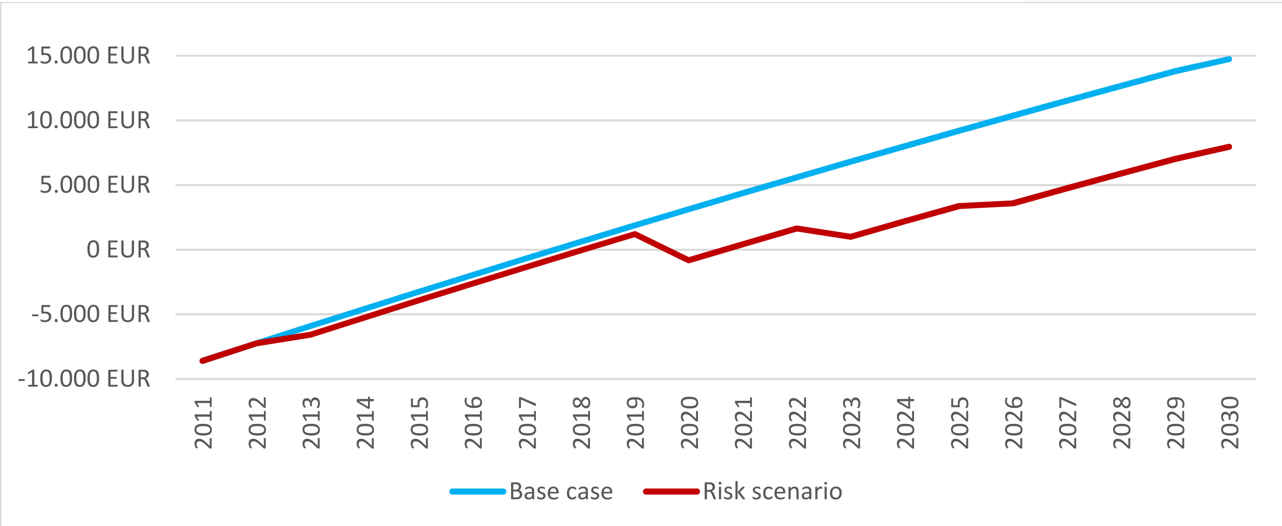


Figure 20: Cumulative cash flow of BM 1

4.3. Impact of Technical Risks on Business Model 2

Business model 2 represents a residential roof-top PV system with a nominal capacity of 5,2 kWp located in southern Germany. The system consists of a single string inverter, two strings with a total of 20 crystalline silicon modules and a lithium storage battery for self-consumption. The system was commissioned in January 2015. The owner is a private investor primarily interested in sustainable solar electricity and relative autonomy from the grid.

4.3.1. Modelling of Single Technical Risks

Table 11 lists twelve single technical risks, each with a best case and worst case version covered by the modelling exercise.

Table 11: List of technical risks of BM 2

Risk number	Name of risk	Case
2000	PID = Potential Induced degradation	Best
2001	PID = Potential Induced degradation	Worst
2010	Failure of bypass diode and juction box	Best
2011	Failure of bypass diode and juction box	Worst
2020	Hotspot of modules	Best
2021	Hotspot of modules	Worst
2030	Theft/ vandalism of modules	Best
2031	Theft/ vandalism of modules	Worst
2040	Fan failure and overheating	Best
2041	Fan failure and overheating	Worst
2050	Lightning strike of inverter	Best
2051	Lightning strike of inverter	Worst
2060	Mismatch of module clamps	Best
2061	Mismatch of module clamps	Worst
2070	UV aging of string cables	Best
2071	UV aging of string cables	Worst
2080	Wrong/Absent cables connection	Best
2081	Wrong/Absent cables connection	Worst
2090	Cabling damaged by rodents	Best
2091	Cabling damaged by rodents	Worst
2100	Failure of battery	Best
2101	Failure of battery	Worst
2110	Failure of battery inverter	Best
2111	Failure of battery inverter	Worst

Nine of the best case failures fall in categories 1 and 2 and three in categories 3 and 4. Ten of the worst case failures fall in categories 3 and 4 and only two in category 2. Module failures cause the highest economic impact with up to 668% followed by inverters with up to 497% of relative revenue losses, which is illustrated in figure 21.

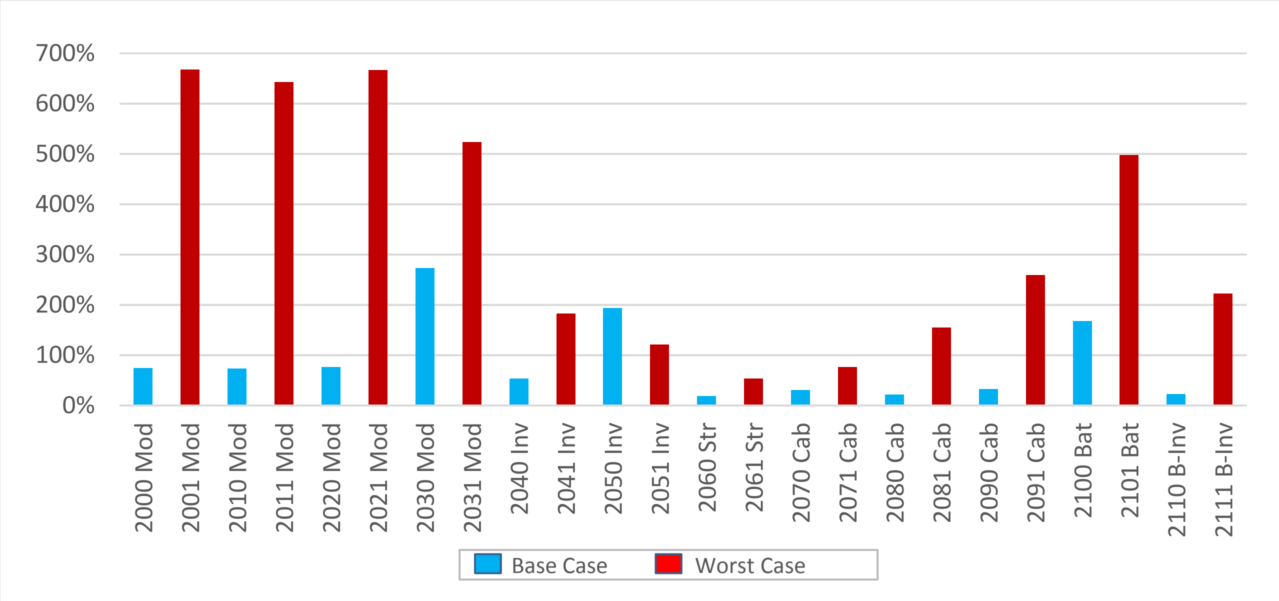


Figure 21: Relative revenue loss by failure of BM 2

The distribution of failure costs as shown in figure 22 varies by type and nature of failure.

- **Repair and substitution costs ($C_{rep/sub}$):** These costs represent more than 50% for failures 2000, 2001, 2010, 2011, 2020, 2021, 2030, 2031, 2050, 2051, 2100 and 2101. The system design with high quality modules and inverters and storage inverter and battery storage is very capital intense, resulting in high repair and substitution costs for spare parts.
- **Detection and fixing costs (C_{det} + C_{fix}):** Labour costs have a dominating influence on failures 2060, 2061, 2070, 2071, 2080, 2090 and 2110. For safety reasons often two people have to be involved in roof-top repair works and one technician has to secure the other.
- **Transportation costs (C_{trans}):** This cost category comprises both transportation and safety costs. The cost influence for most failures is minor, however more significant for utility sized systems where full pallets or containers can be used. Often a crane has to be rented to hoist tools and spare parts on the roof. For extended roof-top repair works the installation of a safety net or scaffold is mandatory.
- **Downtime costs (C_{down}):** Solar electricity losses are significant for failures 2041, 2071 and 2111, reaching up to 44%. They are especially high for failures with a long detection time and failures related to the battery storage system resulting in a loss of self-consumption.

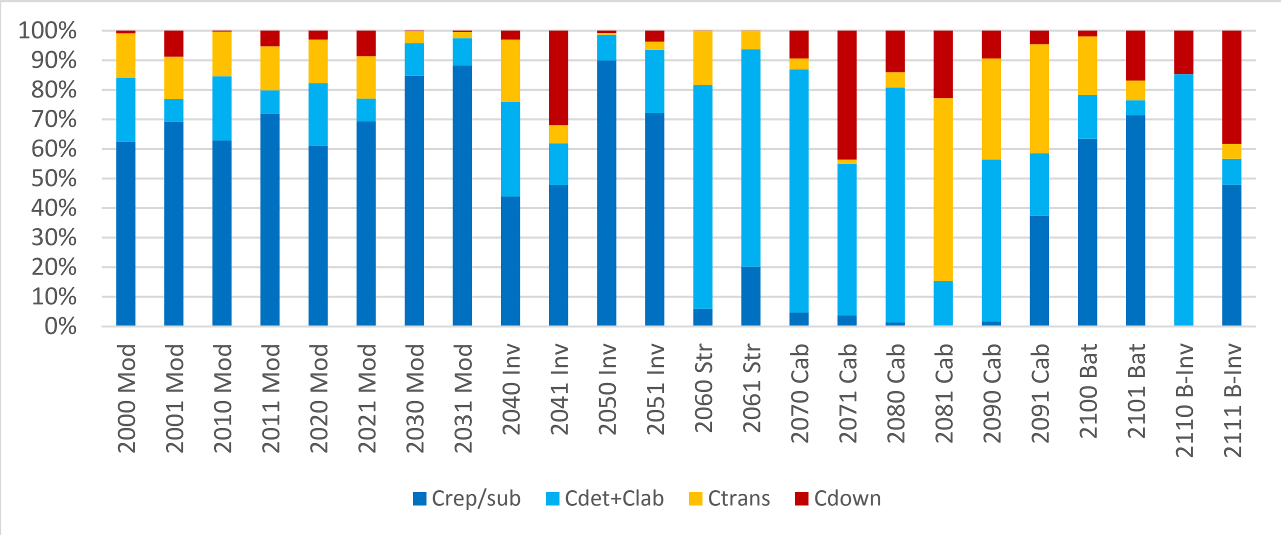


Figure 22: Distribution of failure costs of BM 2

PV systems with battery storage are still almost twice as expensive than pure PV systems. Therefore the base case project IRR of 0.20% for business model 2 is very low. All failures lead to a negative IRR. Among the selected risks a failure of bypass diode and junction box (2011) has the most negative impact and reduces the project IRR to -8.94%. With higher self-consumption rates and rapidly falling battery prices, better IRR are expected for future PV systems with battery storage and self-consumption (see figure 23).

Important Note: In reality most PV systems with battery storage in Germany can take advantage of the KfW "Small Battery Program" which provides a low interest loan and repayment bonus to boost the financial performance. Since the modelling exercise only reflects pure equity funding, the advantages of the KfW program are not reflected in the cash flow analysis and the results of business model 2 cannot be generalized.

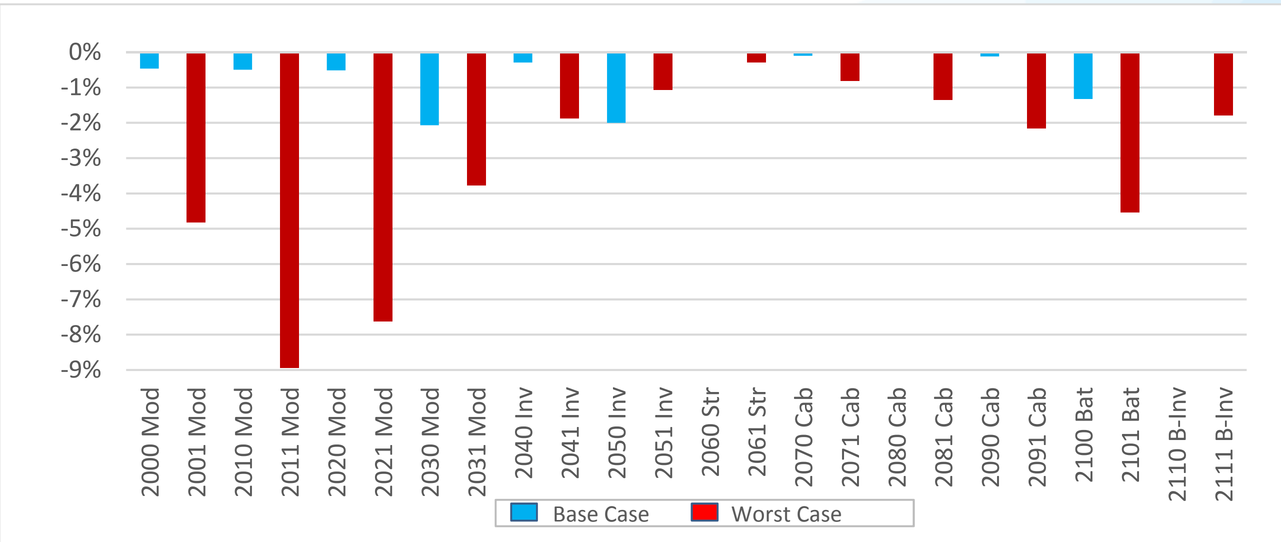


Figure 23: Impact of failure on project IRR of BM 2

4.3.2. Modelling of Technical Risk Scenario

In section 3.3 the following four risks were introduced for the risk scenario modelling of business model as listed in table 12.

Table 12: Risk scenario of BM 2

Risk	Risk number	Risk name	Start Date	Case	Phase
Risk 1	2000	Potential induced degradation	01.01.2015	Best	Infant
Risk 2	2031	Vandalism of modules	01.02.2017	Worst	Infant
Risk 3	2111	Failure of battery inververter	01.03.2023	Worst	Mid-life
Risk 4	2071	UV aging of string cables	01.07.2030	Worst	Wear-out

- **2000 Potential induced degradation of modules:** The manufacturer has delivered two faulty modules, which show a significant power induced performance loss upon operation. The failure is detected at the end of the EPC warranty period during an inspection of the PV system. The two faulty modules are replaced. The failure falls in category 2. The total failure costs are dominated by the costs of spare parts. The owner can try to claim the failure costs from his EPC or from the module manufacturer.
- **2031 Vandalism of modules:** All high quality modules are severly damaged. Due to the lack of an active monitoring sytem the vandalism is only detected after return from a short vacation. All modules are replaced with modules sourced from the secondary market. The failure falls in category 4. Spare part costs represent 89% and labour 8% of total failure costs. The owner can claim the failure costs from his insurer.
- **2111 Failure of battery inverter:** The battery inverter fails before the end of its scheduled service time. Unfortunately the failure remains unnoticed for a longer period of time. Once detected the inverter is replaced. The failure falls in category 4. Spare part costs represent 48% and downtime costs 38% of total failure costs. Downtime costs are high because the difference between the self-consumption tariff and the feed-in tariff is lost. Most likely the failure costs cannot be claimed from any third party. However the base case cash flow model already contains the budget for the exchange of battery inverter after 10-year service life.
- **2071 UV aging of string cables:** In the wear-out phase of the PV system the string cables show signs of UV aging. Upon detection it is decided to replace all string cables because the performance loss of the system is significant. The failure falls in category 2. Downtime cost represent 44% and labour costs 37% of total failure costs. Most likely the failure costs cannot be claimed from any third party. The replacement is still economically viable for the owner if he intends to operate the PV system beyond the 20-year feed-in tariff period.

The failure costs associated with the risk scenario amount to a total of 935% in relative revenue losses. Fixing costs represent 83% and downtime costs 17% (see table 13).

Table 13: Rist scenario results of BM 2

No	Risk	Name of risk	Start date of failure	Total fixing costs of risk C_{fix}	Total down tim costs of risk C_{down}	Total failure costs of risk C_{fail}	IRR (incl failure)	Cumulative cash flow (incl failure)	Relative revenue Loss C_{fail}/R_{12}	Failure categor
1	2000	Potential ind. degradation	01.01.2015	825	8	833	-0,47%	-596	74%	2
2	2031	Theft of modules	01.02.2017	5.865	26	5.891	-3.78%	-5.670	523%	4
3	2071	UV aging of string cables	01.07.2030	484	375	859	-0.81%	-893	76%	2
4	2111	Failure of battery inververter	01.07.2023	1.545	937	2.482	-1.77%	-2.240	220%	4
Total - non discounted static values				8.719	1.805	10.524	-7.65%	-10.282	935%	4

The financial performance for the unleveraged base case of the PV system is very low. The base case project IRR of 0.20% is reduced to -7.65% and the cumulative cash flow over the project lifetime is cut down from EUR 242 to EUR 10,282. (see figure 24).

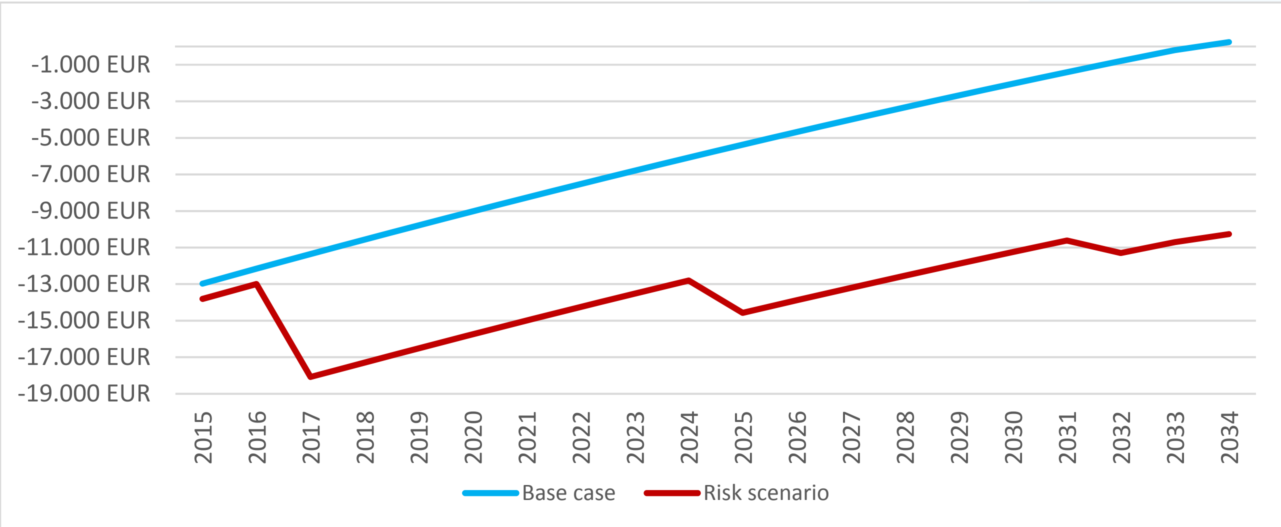


Figure 24: Cumulative cash flow of BM 2

4.4. Impact of Technical Risks on Business Model 3

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

4.4.1. Modelling of Single Technical Risks

Table 14 lists twelve single technical risks, each with a best case and worst case version covered by the modelling exercise.

Table 14: List of technical risks of BM 3

Risk number	Name of risk	Case
3000	PID = Potential Induced degradation	Best
3001	PID = Potential Induced degradation	Worst
3010	Failure of bypass diode/ juction box	Best
3011	Failure of bypass diode/ juction box	Worst
3020	Hotspot of modules	Best
3021	Hotspot of modules	Worst
3030	Theft/ vandalism of modules	Best
3031	Theft/ vandalism of modules	Worst
3040	Fan failure and overheating	Best
3041	Fan failure and overheating	Worst
3050	Lightning strike of inverter	Best
3051	Lightning strike of inverter	Worst
3060	Mismatch of module clamps	Best
3061	Mismatch of module clamps	Worst
3070	UV aging of string cables	Best
3071	UV aging of string cables	Worst
3080	Wrong/Absent cables connection	Best
3081	Wrong/Absent cables connection	Worst
3090	Cabling damaged by rodents	Best
3091	Cabling damaged by rodents	Worst
3100	Flooding of inverter	Best
3101	Flooding of inverter	Worst
3110	Soiling of modules	Best
3111	Soiling of modules	Worst

The utility sized business model 3 is financially robust against the impact of failures. All of the twelve best case failures fall in category 1. Three of the worst case failures fall in categories 3 and 4 and the remaining eight in categories 1 and 2. Module failures cause the highest economic impact with up to 216% followed by cabling with up to 49% of relative revenue losses. It is shown in figure 25.

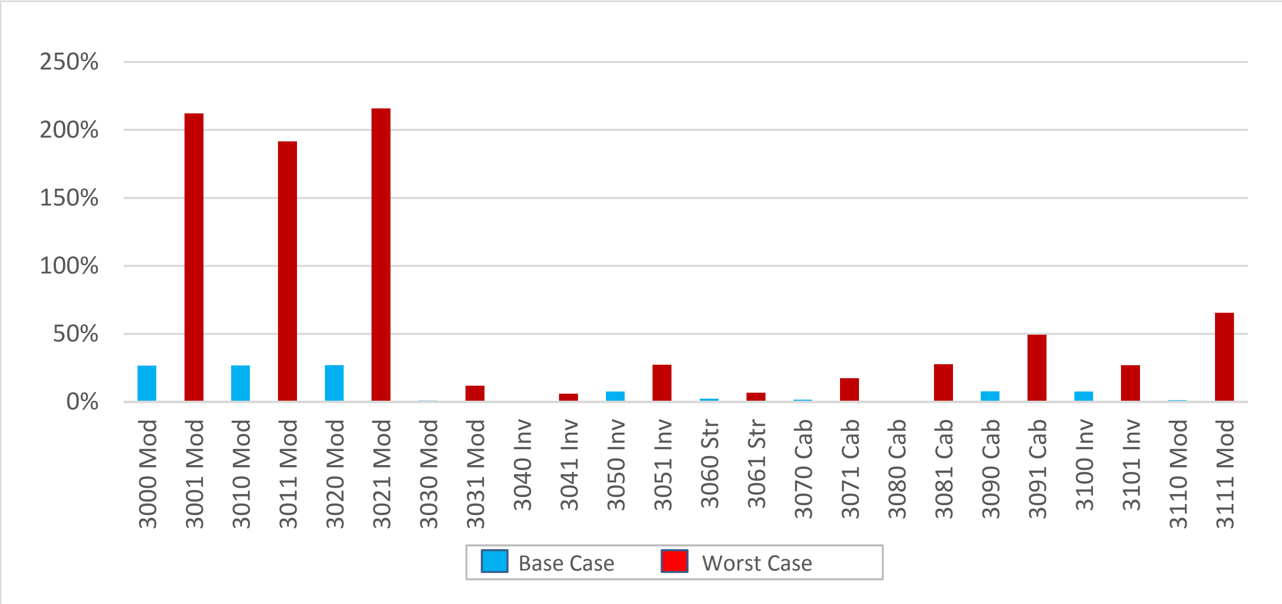


Figure 25: Relative revenue loss by failure of BM 3

The distribution of failure costs varies by type and nature of failure (see figure 26).

- **Repair and substitution costs ($C_{rep/sub}$):** These costs represent more than 50% for failures 3000, 3001, 3010, 3011, 3020, 3021, 3030, 3031, 3050, 3051, 3060, 3061, 3090, 3100 and 3101. In general spare part costs for a utility scale business model tend to be lower than for a residential system.
- **Detection and fixing costs (C_{det} + C_{fix}):** Labour costs have a large influence on failures 3060, 3061, 3070 and 3080. Ground-mounted systems are more accessible and faster to repair than roof-top PV systems.
- **Transportation costs (C_{trans}):** The share of transportation costs are almost negligible for utility scale business models. For worst case failures often a forklift truck has to be rented to handle defective components and spare parts on site.
- **Downtime costs (C_{down}):** Solar electricity losses are dominant for failures 3041, 3071, 3081, 3091, 3110 and 3111, reaching up to 98% in relative revenue losses. The system design is made out of rather large increments with seven central inverters and 22 modules per string. A failure of one component can therefore have an overproportional influence on the downtime costs, especially if the failure is not directly detected upon occurence.

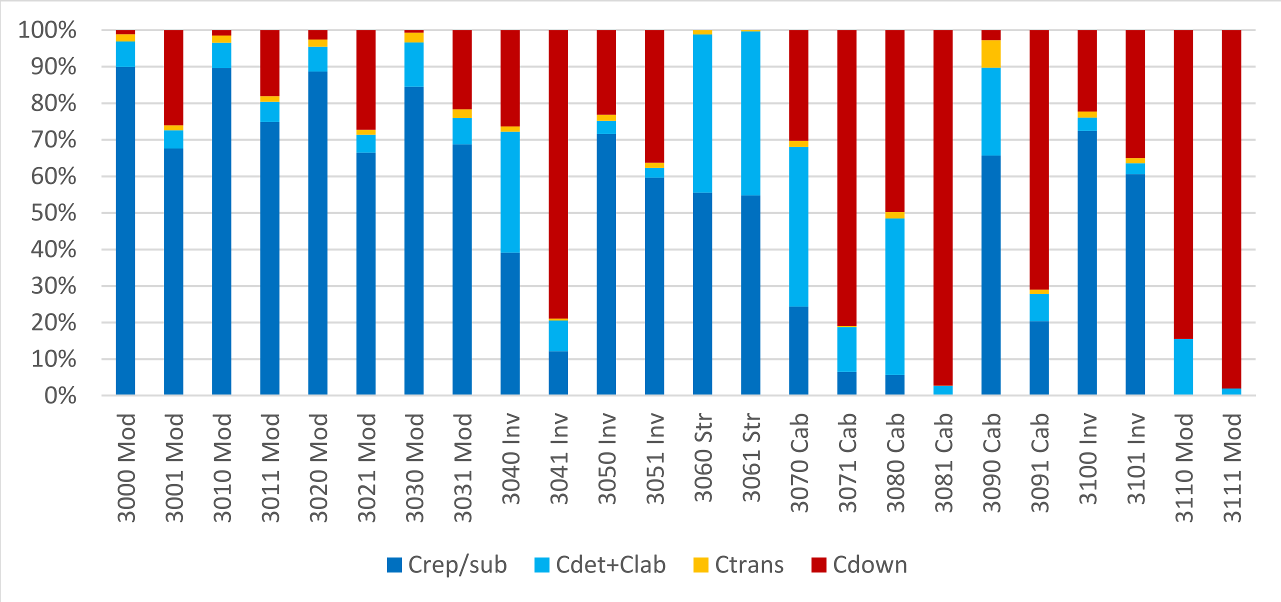


Figure 26: Distribution of failure costs of BM 3

Business model 3 offers a base case project IRR of 5.52%. Most failures belong to a rather low category with limited influence on the financial performance. The highest impact is caused by the worst case of power induced degradation of modules, which reduces the project IRR to 2.68% (see figure 27).

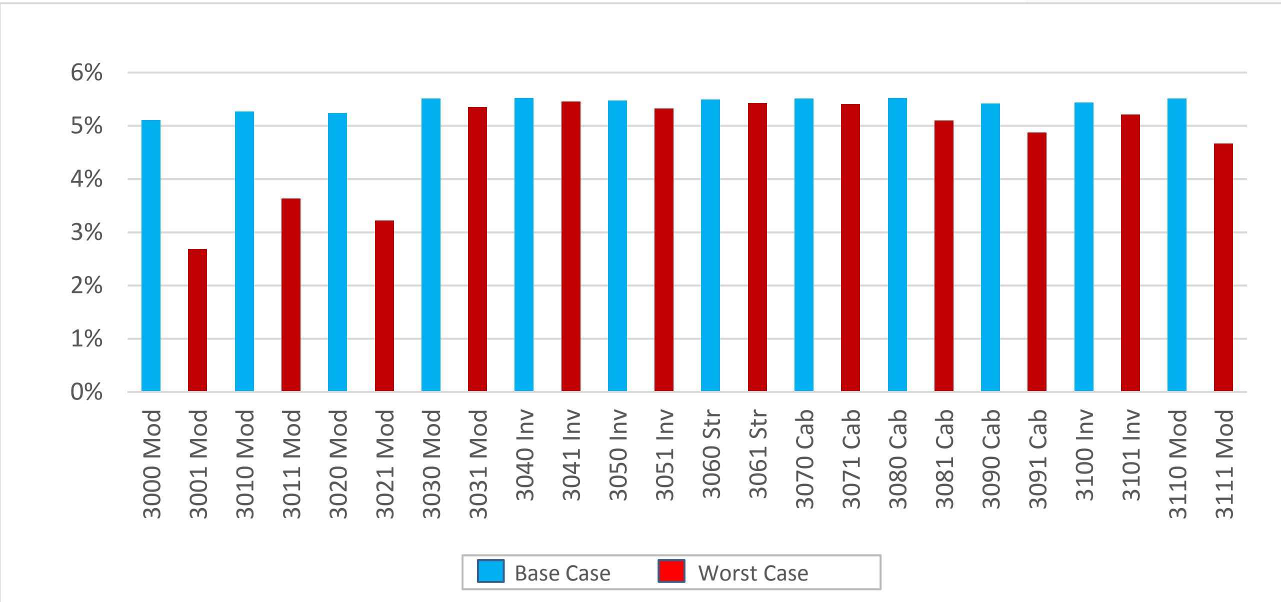


Figure 27: Impact of failure on project IRR of BM 3

4.4.2. Modelling of Technical Risk Scenario

In section 3.3 the following four risks were introduced for the risk scenario modelling of business model 3 as listed in table 15:

Table 15: Risk scenario of BM 3

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

- **3020 Hotspot of modules:** During first year inspection thermography pictures revealed 5% of modules with a hotspot defect. The faulty modules are replaced. The failure falls in category 1. The total failure costs are dominated by the costs of spare parts. The owner can try to claim the failure costs from his EPC or from the module manufacturer.
- **3101 Flooding of inverters:** During a heavy rain three out of the seven central inverters are flooded and need to be replaced. The failure falls in category 1. Spare parts costs represent 61% and downtime losses 35% of total failure costs. Downtime costs are negatively impacted by longer lead times for central than for string inverters. The insurer will check proper flooding zone protection before settling a potential claim.
- **3051 Lightning strike of inverter:** Three central inverters get hit by an intense lightning strike during a thunderstrom. The failure falls in category 1. Spare part costs represent 61% and downtime losses 35% of total failure costs. The owner can claim the failure costs from the insurer.
- **3011 Failure of bypass diode and junction box:** In the wear-out phase of the PV system the humidity is noticed in 30% of the junction boxes, due to a defect of the silicon sealant. All affected modules are replaced. The failure falls in category 3. Spare part costs represent 75% and downtime costs 18% of total failure costs. After more than 15 years of module service life claiming of failure costs from a third party is unlikely.

The failure costs associated with the risk scenario amount to a total of 268% in relative revenue losses. Fixing costs represent 82% and downtime costs 18% (see table 16).

Table 16: Risk scenario results of BM 3

The base case of business model 3 has a project IRR of 5.52%. The risk scenario reduces this IRR

No	Risk	Name of risk	Start date of failure	Total fixing costs of risk C_{fix}	Total down time costs of risk C_{down}	Total failure costs of risk C_{fail}	IRR (incl failure)	Cumulative cash flow (incl failure)	Relative revenue Loss C_{fail}/R_{12}	Failure category
1	3020	Hotspot of modules	01.01.2012	301.397	7.137	308.534	5.12%	5.271.398	27%	1
2	3101	Flooding of inverter	01.08.2017	200.856	108.369	309.225	5.21%	5.270.708	9%	1
3	3051	Lightning strike of inverter	01.06.2020	200.216	117.671	317.887	5.24%	5.262.045	28%	1
4	3011	Failure bypass diode/junct.	01.10.2026	1.800.535	332.118	2.132.653	4.06%	3.447.280	186%	3
Total - non discounted static values				2.503.004	565.295	3.068.299	2.92%	2.511.633	268%	4

to 2.92%. The cumulative cash flow over the project lifetime, as shown in figure 28, is cut from EUR 5,579,932 to EUR 2,511,633 (see figure 28).

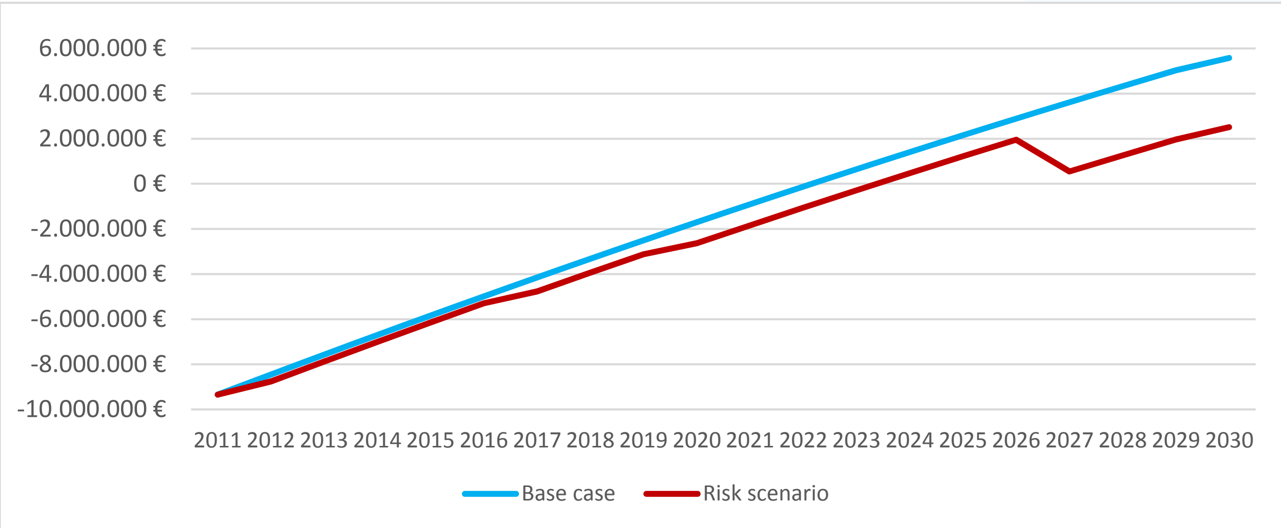


Figure 28: Cumulative cash flow of BM 3

4.5. Impact of Technical Risks on Business Model 4

Business model 4 is a utility scale ground mounted PV system with a nominal capacity of 662.6 kWp located in northern Italy. The system is made of 75 string inverters with 12 strings per inverter and 10 CdTe thin-film modules per string. The system was commissioned in July 2010. The owner Is a strategic investor interested in financial returns and increase of his renewable electricity share.

4.5.1. Modelling of Single Technical Risks

Table 17 lists twelve single technical risks, each with a best case and worst case version covered by the modelling exercise.

Table 17: List of technical risks of BM 4

Risk number	Name of risk	Case
4000	Low power/TCO corrosion of modules	Best
4001	Low power/TCO corrosion of modules	Worst
4010	Failure of bypass diode and juction box	Best
4011	Failure of bypass diode and juction box	Worst
4020	n.a.	Best
4021	n.a.	Worst
4030	Theft/ vandalism of modules	Best
4031	Theft/ vandalism of modules	Worst
4040	Fan failure and overheating	Best
4041	Fan failure and overheating	Worst
4050	Lightning strike of inverter	Best
4051	Lightning strike of inverter	Worst
4060	Mismatch of module clamps	Best
4061	Mismatch of module clamps	Worst
4070	UV aging of string cables	Best
4071	UV aging of string cables	Worst
4080	Wrong/Absent cables connection	Best
4081	Wrong/Absent cables connection	Worst
4090	Cabling damaged by rodents	Best
4091	Cabling damaged by rodents	Worst
4100	Glass breakage of module, frameless	Best
4101	Glass breakage of module, frameless	Worst

All ten best case failures fall in category 1. The worst case failures are spread across several categories, seven in category 1, two in category 2 and one in category 3. The highest economic impact is caused by modules with up to 120% of relative revenue losses, which can be seen in figure 29.

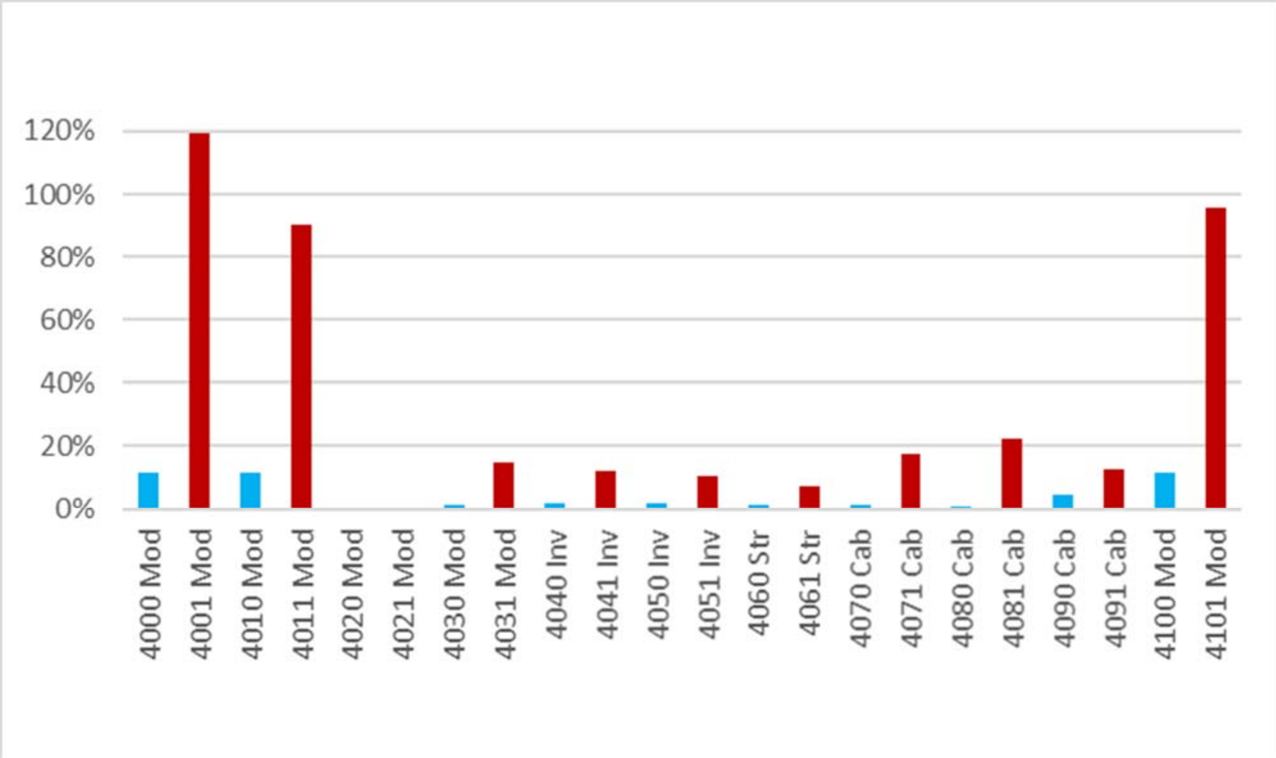


Figure 29: Relative revenue loss of BM 4

The distribution of failure costs varies by type and nature of failure (see figure 30).

- **Repair and substitution costs ($C_{rep/sub}$):** These costs represent more than 50% for failures 4000, 4010, 4011, 4030, 4031, 4040, 4041, 4050, 4051, 4061 and 4100. Spare modules are normally still available from the secondary market. New compatible string inverters are often available with a higher efficiency and allow to improve the overall system performance.
- **Decection and fixing costs (C_{det} + C_{fix}):** Labour costs have a large influence on failures 4060, 4061, 4070 and 4080. Ground mounted systems are more accessible and faster to repair than roof-top PV systems. The CdTe modules with a nominal capacity of only 77.5 Wp are somewhat more labour intense than high power crystalline modules.
- **Transportation costs (C_{trans}):** The share of transportation costs for CdTe modules is higher than for crystalline modules. For worst case failures often a fork lift truck has to be rented to handle defective components and spare parts on site. The replacement of modules requires a registragion of the new modules with the grid operator GSE, which can be quite time consuming.
- **Downtime costs (C_{down}):** Solar electricity losses have a large influence on failures 4001, 4071 and 4081, reaching up to 92%. The system design consists of many small increments. A failure of one component therefore causes limited downtime costs. With a proper monitoring system even smaller losses can be detected in an early stage.

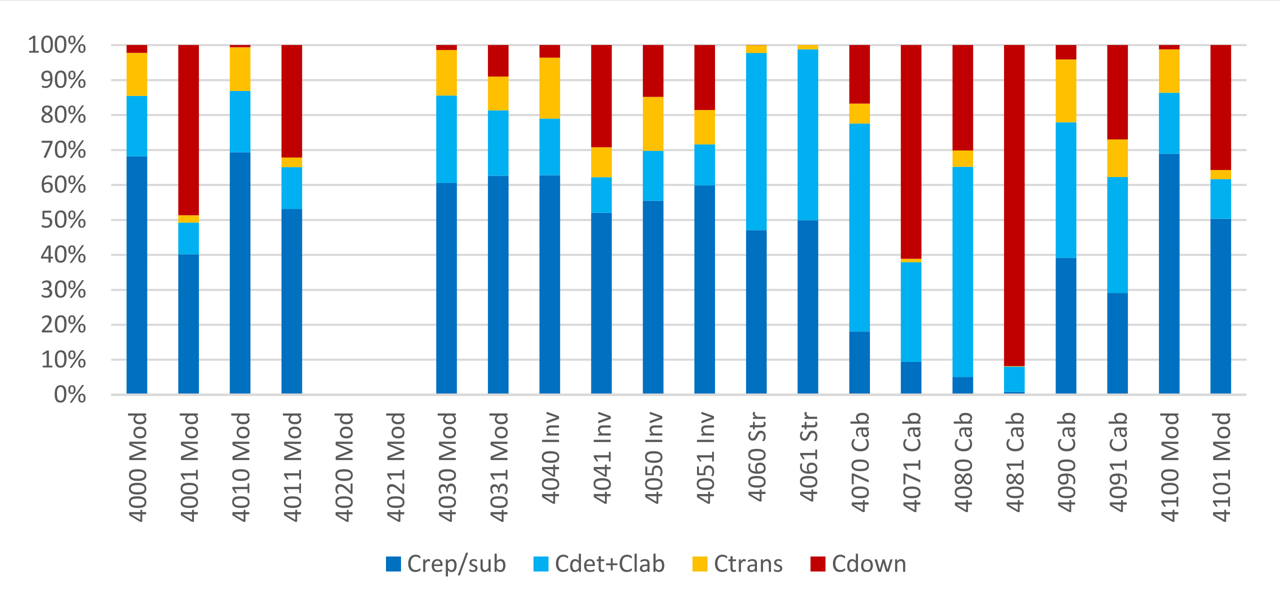


Figure 30: Distribution of failure costs of BM 4

Business model 4 offers an attractive base case project IRR of 10.74%. Most failures belong to a rather low category with limited influence on the financial performance. The business model proves to be very robust. The highest impact, as can be seen in figure 31, is caused by the worst case of low power/TCO corrosion of modules, which reduces the project IRR to 8.56% (see figure 31).

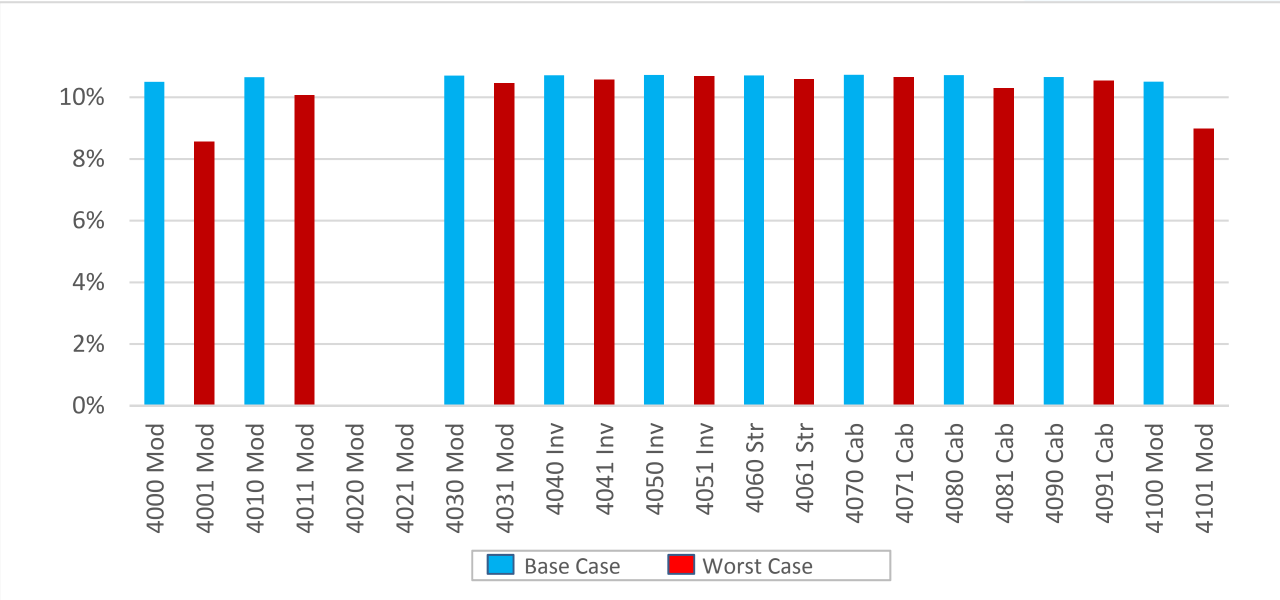


Figure 31: Impact of failure on project IRR of BM 4

4.5.2. Modelling of Technical Risk Scenario

In section 3.3 the following four risks were introduced for the risk scenario modelling of business model 4 as listed in table 18.

Table 18: Risk scenario of BM 4

Risk	Risk number	Risk name	Start Date	Case	Phase
Risk 1	4001	Low power/TCO corrosion of module	01.07.2010	Worst	Infant
Risk 2[2)]	4101	Glass breakage of module, frameless	01.01.2011	Worst	Infant
Risk 3[1)]	4031	Vandalism of modules	01.02.2015	Worst	Mid-life
Risk 4	4081	Wrong/Absent cables connection	01.07.2025	Worst	Wear-out

- **4001 Low power/TCO corrosion of module:** In the infant operations phase the PV system shows a massive underperformance. An onsite inspection reveils that the modules are the root cause of the failure. The affected modules are distributed across all strings affecting the performance of the entire PV system. The faulty modules are replaced. The failure falls in category 3. The total failure costs are dominated by 49% downtime and 40% spare parts costs. The owner can try to claim the failure costs from his EPC respectively from the module manufacturer under the performance guarantee.
- **4101 Glass breakage of module:** During the first winter season heavy snow loads cause glass breakage of the frameless modules. One third of the modules are affected and have to be replaced. The failure falls in category 2. Failure costs are dominated by 50% spare parts and 36% downtime costs. The owner can try to claim the failure costs from his insurer.
- **4031 Vandalsim of modules: :** In a vandalism attack 500 modules are destroyed and have to be replaced. The failure falls in category 1. Spare parts represent 63% and labour 19% of total failure costs. The owner has met all security requirements and can claim the failure costs from the insurer.
- **4081 Wrong/absent cable connection:** A mismatch of connectors leads to a humidity based performance loss. 270 faulty connectors have to be replaced. The failure falls in category 1. Failure costs are dominated by 92% downtime costs. After more than 15 years of service life refund of failure costs from a third party is unlikely.

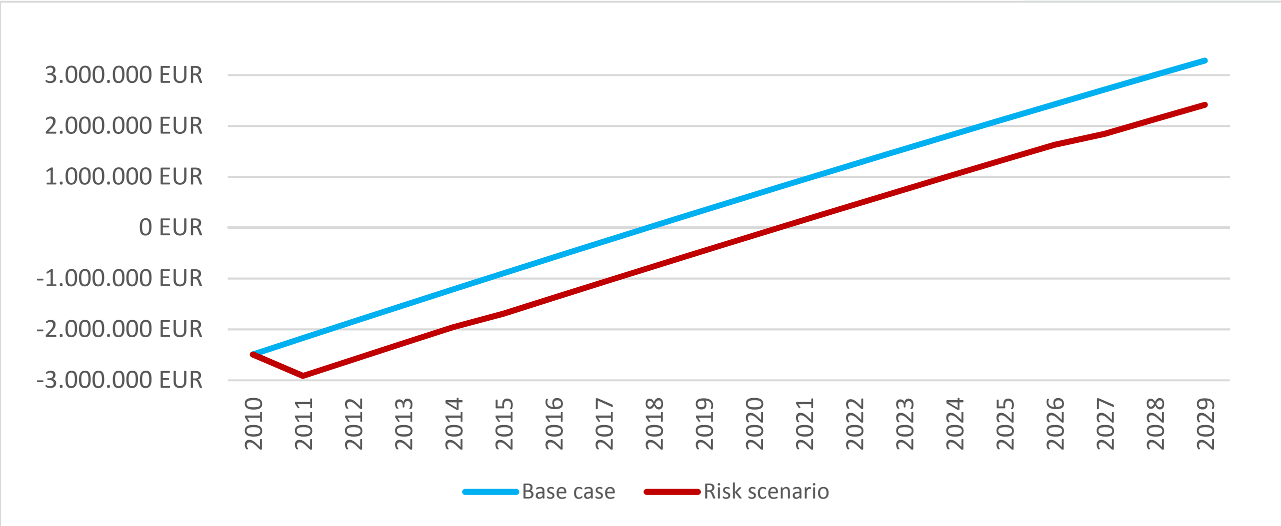
The failure costs associated with the risk scenario amount to a total of 260% in relative revenue losses. Fixing costs represent 53% and downtime costs 47% (see table 19).

Table 19: Risk scenario results of business model 4

No	Risk	Name of risk	Start date of failure	Total fixing costs of risk C_{fix}	Total down tin costs of risk C_{down}	Total failure costs of risk C_{fail}	IRR (incl failure)	Cumulative cash flow (incl failure)	Relative revenue Loss C_{fail}/R_{12}	Failure catego
1	4001	LP/TCO corrosion of CdTe mod.	01.07.2010	212.386	201.554	413.940	8.57%	3.036.017	120%	3
2	4101	Glass breakage of module	01.01.2011	212.386	118.075	330.461	9.01%	3.119.496	96%	2
3	4031	Theft/ vandalism of modules	01.02.2015	47.120	4.611	51.731	10.55%	3.398.227	15%	1
4	4081	Wrong/absent cables connec.	01.07.2025	6.299	65.787	72.085	10.%	3.377.872	21%	1
Total - non discounted static values				478.191	422.763	900.954	6.78%	2.549.004	260%	4

The financial performance of PV system is negatively impacted by the risk scenario. The base case project IRR of 10.74% is reduced to 6.78% and the cumulative cash flow over the project lifetime is cut down from EUR 3,449,957 to EUR 2,549,004 (see figure 32).

Figure 32: Cumulative cash flow of BM 4



4.6. Risk Mitigation measures

The Solar Bankability report "Minimizing Technical Riks in Photovoltaik Projects" introduces a detailed description of all suitable risk mitigation measures [11] (see table 20). In a scenario analysis the reduction of total failure costs is described for different combinations of mitigation measures.

Table 20: List of most significant risk mitigation measures

Mitigation Measure	Affected Parameter
Component testing – PV modules	number of failures
Design review + construction monitoring	number of failures
Qualification of EPC	number of failures
Advanced monitoring system	time to detection
Basic monitoring system	time to detection
Advanced inspection	time to detection
Visual inspection	time to detection
Spare part management	time to repair/substitution

- **Component testing** of important plant components such as PV modules or inverters. The testing can be carried out at the the production site, at a certified test laboratory or on-site at the PV plant.
- **Design review and construction monitoring** serves to identify issues caused by bad PV plant conception and poor installation workmanship.
- **Qualification of EPC** focuses on ensuring the competencies of the field workers, e.g., by requiring certain technical qualification prerequisites or regular training of field workers
- **Advanced monitoring system** serves for early detection and diagnosis of faults
- **Basic monitoring system** is used to monitor plant level alarms and notifications
- **Advanced inspection** to detect defects not usually visible with naked eyes, e.g., infrared or electroluminiscence camera
- **Visual inspection** to identify any visible changes in PV plant components
- **Spare part management** to minimize downtime and repair/substituion costs

The Solar Bankability report "Best Practice Guideline for PV Cost Calculation" introduces the concept of risk categorisation flash cards and further provides a sensitivity analysis on the impact of mitigation measures on CAPEX, OPEX and yield [12].

The general classification method for the impact of mitigation measures provided in the Solar Bankability report "Minimizing Technical Riks in Photovoltaik Projects" has been transferred to the risks of the four business models under consideration.

Table 21: Impact list of mitigation measures applied to single technical risks

Risk	Name of risk	Component testing	Design review + construction monitori	Qualification of EPC	Advanced monitoring system	Basic monitoring syst	Advanced inspection	Visual inspection	Spare part manageme
xx00	PID = Potential Induced degradation	High	-	-	-	-	Medium	-	High
xx01	PID = Potential Induced degradation	High	-	-	-	-	Medium	-	High
xx10	Failure of bypass diode and juction box	High	-	-	High	Medium	Medium	Medium	High
xx11	Failure of bypass diode and juction box	High	-	-	High	Medium	Medium	Medium	High
xx20	Hotspot of modules	High	-	-	-	-	Medium	-	High
xx21	Hotspot of modules	High	-	-	-	-	Medium	-	High
xx30	Theft/ vandalism of modules	-	-	-	High	High	Medium	Medium	High
xx31	Theft/ vandalism of modules	-	-	-	High	High	Medium	Medium	High
xx40	Fan failure and overheating	-	Medium	Medium	High	Medium	Medium	Medium	High
xx41	Fan failure and overheating	-	Medium	Medium	High	Medium	Medium	Medium	High
xx50	Lightning strike of inverter	-	-	-	High	Medium	Medium	Medium	High
xx51	Lightning strike of inverter	-	-	-	High	Medium	Medium	Medium	High
xx60	Mismatch of module clamps	-	High	Medium	-	-	Medium	Medium	-
xx61	Mismatch of module clamps	-	High	Medium	-	-	Medium	Medium	-
xx70	UV aging of string cables	-	High	Medium	-	-	Medium	Medium	Low
xx71	UV aging of string cables	-	High	Medium	-	-	Medium	Medium	Low
xx80	Wrong/Absent cables connection	-	HIgh	Medium	High	Medium	Medium	Medium	Low
xx81	Wrong/Absent cables connection	-	HIgh	Medium	High	Medium	Medium	Medium	Low
xx90	Cabling damaged by rodents	-	-	-	High	Medium	Medium	Medium	Low
xx91	Cabling damaged by rodents	-	-	-	High	Medium	Medium	Medium	Low
1100	Module breakage by hail	-	-	-	High	Medium	Medium	Medium	High
1101	Module breakage by hail	-	-	-	High	Medium	Medium	Medium	High
1110	Soiling of modules	-	-	-	High	Medium	Medium	Medium	-
1111	Soiling of modules	-	-	-	High	Medium	Medium	Medium	-
2100	Failure of battery	-	-	-	High	Medium	Medium	Medium	High
2101	Failure of battery	-	-	-	High	Medium	Medium	Medium	High
2110	Failure of battery inververter	-	-	-	High	Medium	Medium	Medium	High
2111	Failure of battery inververter	-	-	-	High	Medium	Medium	Medium	High
3100	Flooding of inverter	-	High	Medium	High	Medium	Medium	Medium	High
3101	Flooding of inverter	-	High	Medium	High	Medium	Medium	Medium	High
3110	Soiling of modules	-	-	-	High	Medium	Medium	Medium	-
3111	Soiling of modules	-	-	-	High	Medium	Medium	Medium	-
4100	Glass breakage of module, frameless	-	-	-	High	Medium	Medium	Medium	High
4111	Glass breakage of module, frameless	-	-	-	High	Medium	Medium	Medium	High

The above table 21 describes the impact of theoretical risk mitigation measures. Under real terms the investor has to make an individual cost benefit analysis and define what budget they are prepared to invest in risk mititagion measures and how much of their base case profitability they are willing to "sacrifice" for the improved quality of the PV system and the enhanced stability of the cash flow model.

For the business models 1 to 4 the following risk mitigation measures are being covered by the base case of the cash flow model (table 22):

Table 22: Risk mitigation measures covered by base case cash flow model

Business Modell	Component testing	Design review + constrution monitoring	Qualification of EPC	Advanced monitoring system	Basic monitoring system	Advanced inspection	Visual inspection	Spare part management
BM 1	covered	covered	covered	-	covered	-	covered	-
BM 2	-	-	-	-	covered	-	covered	-
BM 3	covered	covered	covered	covered	-	covered	covered	-
BM 4	covered	covered	covered	covered	-	covered	covered	partially

Business model 1: The owner works for an EPC therefore he can take advantage of a couple of mitigation measures free of charge. He implements the basic monitoring and visual inspection himself at no extra cost. Besides an IRR of 13.58% the business model shows a good level of risk protection.

Business model 2: The owner is a private house owner without own technical knowledge. He has to rely on the component testing, design and installation qualification of his EPC. He implements the basic monitoring through a webportal and carries out regular visual inspections himself. The business model shows both a low IRR of 0.20% and a low level of risk protection

Business model 3: The owner is a financial investor. Given the size of the project he has obtained third party advice to take care of component testing, design and construction review. Advanced monitoring and inspections are covered by an ongoing operations and maintenance contract. The business model offers a good balance between an IRR of 5.52% and a professional risk protection.

Businss model 4: The owner is a strategic investor with sufficient inhouse knowledge for component testing, design and installation review and qualified EPC selection. Advanced monitoring and inspection are covered by an ongoing operations and maintenance contract. Some spare parts are kept in inventory to minimize potential downtime of central inverters. The business model offer an IRR of 10.47% together with a professional risk protection.

In most cases utility scale PV systems are more likely to possess a professional level of risk protection. However owners of small residential and commercial systems often overestimate the “maintenance free investment” argument. In light of the findings from the Solar Bankability project it is recommended to critically question this statement and to design a customized portfolio of risk mitigation measures for each PV system with optimized time intervals and budgets. Besides regular visual inspections and/or ongoing monitoring by the owner the costs for a PV system check at commissioning, a check at the end of the EPC/module warranty and a midlife inspection should be budgeted as minimum risk protection. These measures, if well documented, can have a positive impact on the terms of the credit agreement or insurance contract. Figure 33 shows the minimum risk protection as well as the occurrence of risks for smaller PV systems against the background of the project lifecycle.

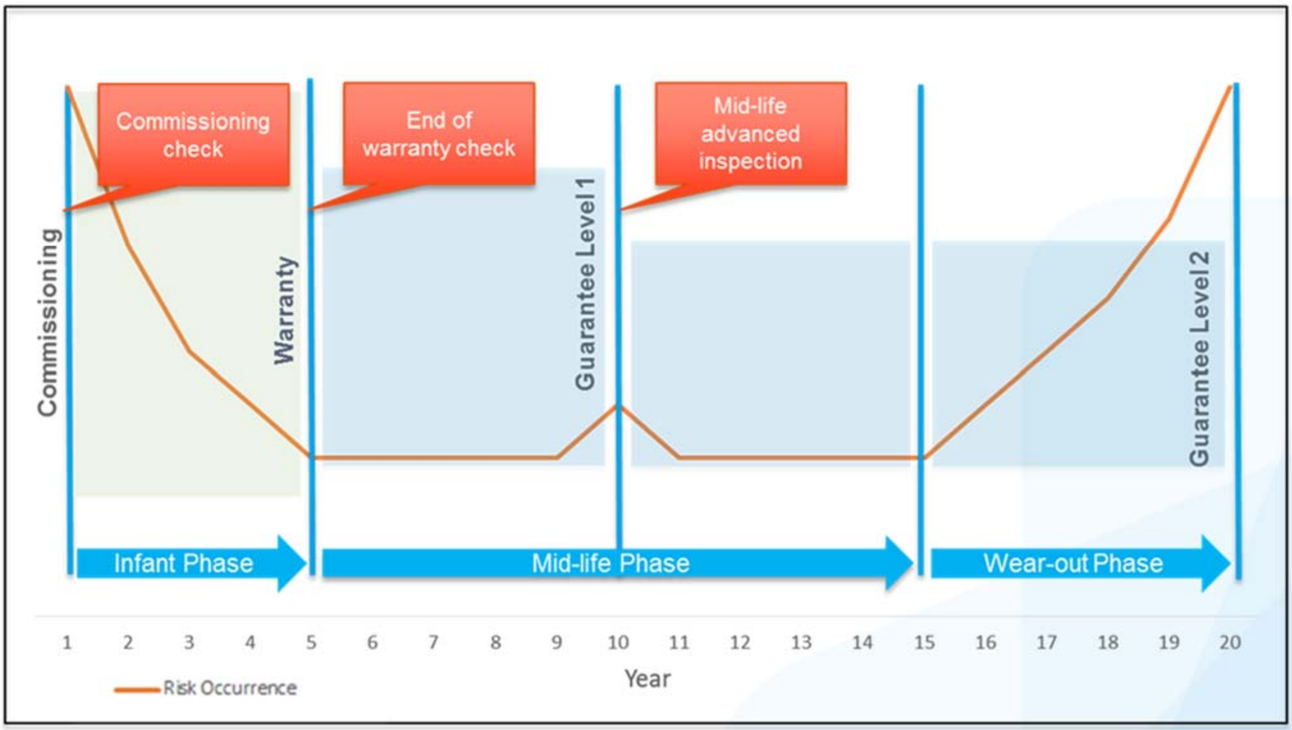


Figure 33: Minimum risk protection versus risk occurrence for smaller PV systems

5. Impact of New Capital Market Regulations

5.1. Financial Crisis 2008

On September 15, 2008, the Investment Bank Lehman Brothers filed for bankruptcy. This largest bankruptcy in history triggered a credit crunch in the global capital markets. Central banks around the world adjusted their monetary policy immediately. At first they reduced their interest rates to almost zero to inject liquidity and later they introduced quantitative easing measures to stabilise the markets. In order to prevent a similar disruption in the future and to enhance transparency and stability in global capital markets, regulatory bodies started to develop a new capital market framework based on three pillars [13] as depicted in figure 34:

- 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.

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

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

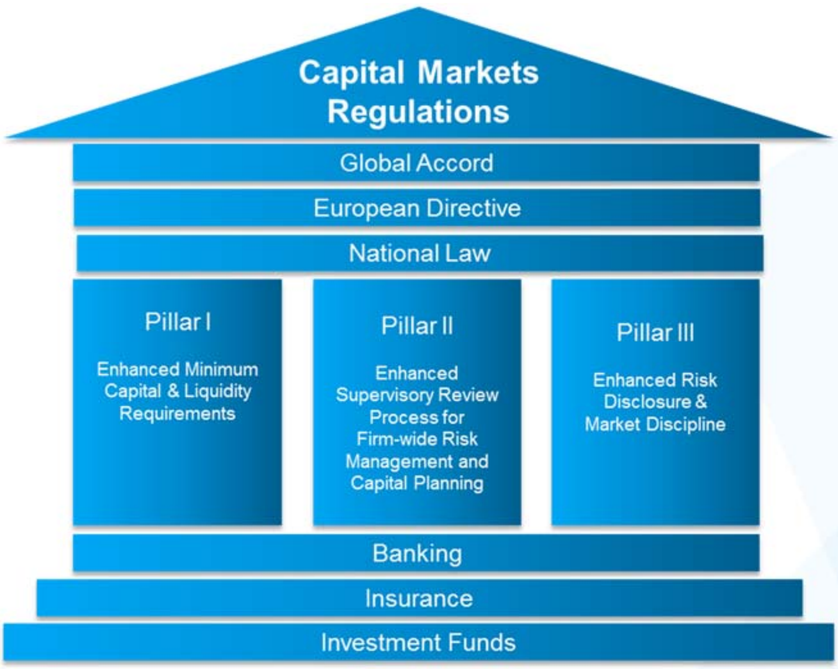


Figure 34: Three pillar model on new capital markets regulations

5.2. Impact of New Banking Regulations

In December 2010 the Basel Committee on Banking Supervision published Basel III [14], a regulatory framework for more resilient banks and banking systems. A more comprehensive and detailed framework was published on Capital Rules in June 2011 [15], on Liquidity Coverage Ratio (LCR) and Liquidity Monitoring Tools in January 2013 [16], and on Net Stable Funding Ratio (NSFR) in October 2014 [17]. The European Union has converted this framework into a series of EU directives and regulations [18/19/20]. The phase-in arrangements schedule full implementation of this new regulatory framework on a national level by 2019.

The Liquidity Coverage Ratio is meant as a protection against short term liquidity disruptions. This ratio ensures that banks hold sufficient stock of “high quality liquid assets” to cover their liquidity needs for 30 calender days under a predefined stress scenario. Photovoltaic projects - typically funded through long-term project finance or special purpose vehicles - neither qualify as high quality liquid assets nor do they receive any preferential treatment on the undrawn portion of liquidity facilities. For undrawn liquidity, i.e. during the construction phase, a 100% coverage will be required. With the gradual phase-in of the LCR potentially the amount of capital available for financing renewable energy projects might be reduced and the interest rates involved might be increased [21].

The Net Stable Funding Ratio tries to limit an overreliance of banks on short-term funding. The NSFR ensures the availability of sufficient stable funding in relation to the liquidity risk profile over a one-year horizon under a predefined stress scenario. Renewable energy projects such as PV require a stable funding factor of 100%. It means that in order to finance a renewable energy project for over one year, banks are required to maintain stable funding for at least the same duration of time in order to back the loan. The stable funding requirements might potentially lead to either higher lending costs or to a shortening of lending terms from 10-18 years to 5 to 7 years requiring subsequent repayment or refinancing [21].

Banks will have two options to meet the enhanced requirements for risk assessment, management and disclosure. They can either enhance their own risk management system and build up an inhouse 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 [22, 23].

In light of LCR and NSFR, banks might increasingly consider to offload long-term renewable energy debt from their balance sheet and to structure large PV projects or projet portfolios into individual bonds, i.e. under the voluntary Green Bond Principles [21], which can be sold to investors with a need for long-term stable cashflows such as pension funds or insurances.

5.3. Impact of New Insurance Regulations

The Solvency II regulatory regime replaces 14 existing insurance directives and introduces for the first time a robust, harmonised framework for insurance firms in the EU [24]. This statutory frameworks is based on the individual risk profile of each insurance firm and aims at promoting transparency, comparability and competitiveness. The Solvency II directive was published in November 2009 [25] and later amended by the Omnibus II directive in April 2014 [26]. The entire Solvency II regime has become fully applicable in January 2016.

Under pillar I the Solvency II regime establishes market-consistent rules for the valuation of assets and liabilities. It introduces the Minimum Capital Requirement (MCR) as measure for the minimum acceptable capital security level and the Solvency Capital Requirement (SCR) [27] as solvency security level for own funds over a one year period under a predefined stress scenario. Under these rules insurers were reluctant to invest in infrastrucure projects, hence these investments represented less than 0.3% of their total assets by 2015 [28, 29].

In September 2015 the European Union published the Capital Markets Union [30], an action plan to mobilise capital in Europe and channel it to long-term infrastructure and sustainable projects. A major source of these investments is supposed to come from large institutional investors such as insurers and pension funds. To facilitate such investments the Solvency II Delegated Regulations have been amended to better incentivise insurers to invest in infrastrucure projects, in particular by reducing the amount of capital which insurers must hold against the debt and equity of qualifying infrastructure projects. Infrastructure assets are defined as physical structures or facilities, systems and networks that provide or support essential public services.

From now on qualifying infrastructure investments will form a distinct asset category under Solvency II and will benefit from an appropriate risk calibration, lower than that which would otherwise apply (for example the calibration of the stress factor for such an investment in equity is lowered from 49% to 30%). This will ultimately lead to a lower capital charge.

Qualifying infrastructure investment must meet a number of criteria specified by the European Insurance and Occupational Pensions Authority (EIOPA) [31]. These criteria aim to provide a high degree of protection and security and predictable cash flows for investors. The insurer is required to implement thorough due diligence and an ongoing risk management procedures. For investments in bonds or loans, the insurer must also demonstrate that he is able to hold the investment to maturity. It is not necessary for an investment to be externally rated, but if not rated (or if the investment is in equities) additional criteria must be met. Rated infrastructure debt investments must be investment grade to receive a reduced capital charge.

Given the low exposure to infrastructure investments of less than 0.3% of total assets, insurers will have to develop a professional understanding of renewable energy projects in order to meet the risk management requirements set out under the Solvency II regime. While a few of the large insurance and reinsurance firms have decided to set-up specialised in-house PV teams, other insurance firms have opted to rely on the support of external PV rating and asset management services.

5.4. Impact of New Investment Funds Regulations

The regulatory regime for investment funds which are managed or marketed in the European Union can be divided in the UCITS and the AIFM Directives. Whilst the UCITS IV Directive [32], published in January 2009, and the UCITS V Directive [33], published in July 2014, both address collective investments in transferable securities, the AIFM Directive (AIFMD), published in November 2010 [34], addresses alternative investments, i.e. in private equity, real estate, infrastructure or hedge funds.

The overarching objective of the AIFMD is to create - for the first time - a comprehensive and secure framework for the supervision and prudential oversight of AIFM in the EU [35]. Once the AIFMD enters into force, all AIFM are required to obtain authorisation and are liable to ongoing regulation and supervision. In this way, the AIFMD will:

- Increase the transparency of AIFM towards investors, supervisors and the employees of the companies in which they invest;
- Provide national supervisors, the European Securities Markets Agency (ESMA) and the European Systemic Risk Board (ESRB) with the information and tools necessary to monitor and respond to risks to the stability of the financial system that could be caused or amplified by AIFM activity;
- Introduce a common and robust approach for the protection of investors in these funds;
- Strengthen and deepen the single market, always liable to high and consistent regulatory standards, thereby creating the conditions for increased investor choice and competition throughout the EU; and
- Increase the accountability of majority stakes (private equity) of AIFM holdings in companies towards employees and the public at large.

The AIFMD winners are large funds that have the resources and structures to take the AIFMD's regulatory burden. Small fund boutiques, which have been pushing investments in renewable energies with innovative fund concepts, will potentially lose out.

EU Member States were required to transpose the AIFM Directive into national law by 22 July 2013. Implementation of the AIFM Directive will help to overcome some of the negative side effects of grey market funds and the ongoing debate on shadow banking.

5.5. Overall Impact of New Capital Market Regulations

New capital market regulations will only have a minor side-effect on the overall risk distribution. Enhanced risk management systems will increase the bureaucratic burdon and associated costs. Comments from the Public Advisory Board and the 1st Public Workshop of the Solar Bankability project reveil that many different risk categories have to be reflected in the risk rating of PV projects. The example of the DiaCore study [36] on risks in renewable energy investments shows that the importance of financing risks are by far outweighed by other risk categories.

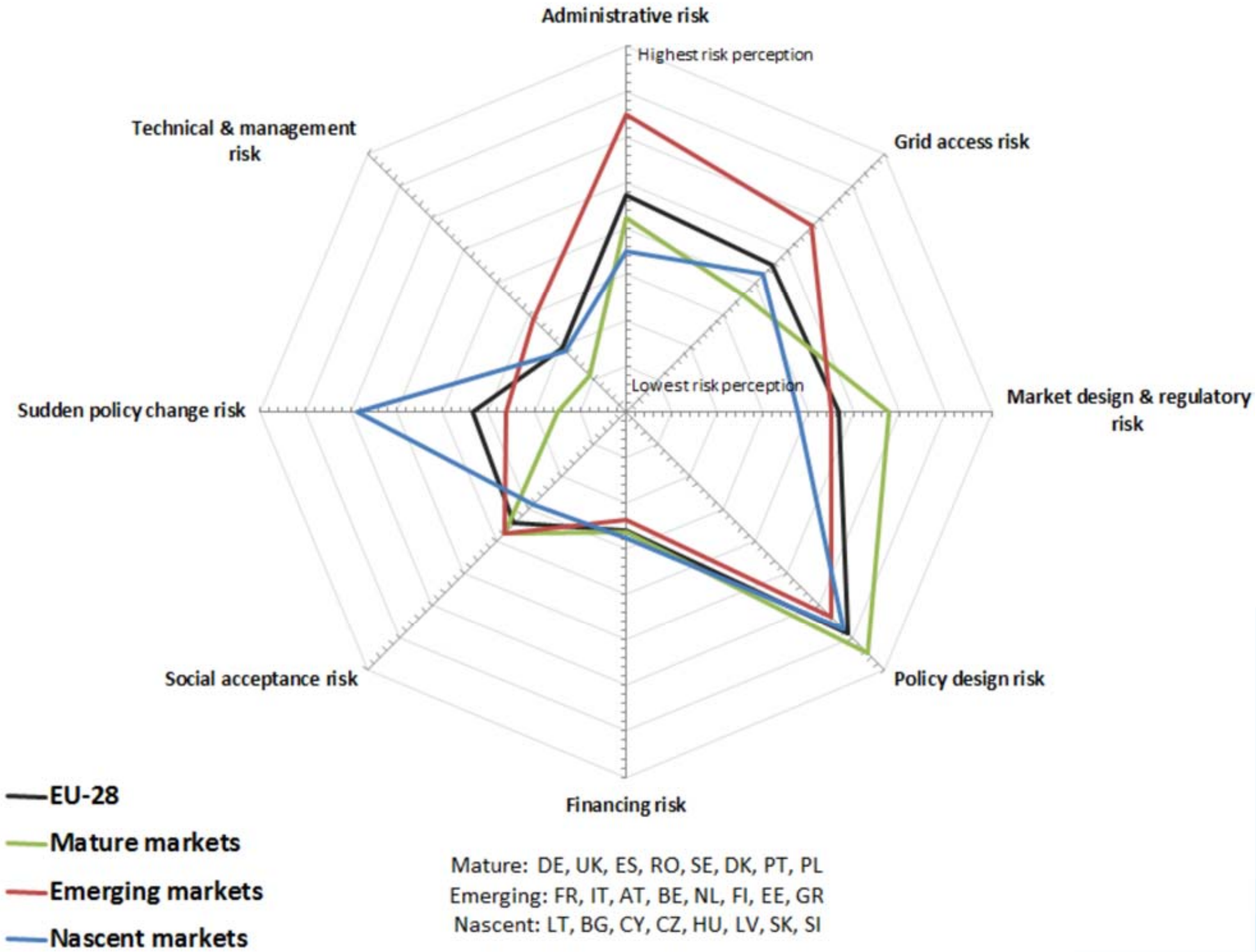


Figure 35: Average ranking of risks for on-shore wind across EU member states [36]

Other influencing factors have a far bigger impact on recent development trends in the European PV market:

- Due to rapid cost reductions accompanied by significant efficiency increases, PV system prices have come down by approximately 70% since 2008.
- PV investment climate has been adversely affected by reductions, discontinuation or retroactive cuts of incentive schemes in many national markets.
- Annual installation levels in Europe have peaked at 22.2 GWp in 2011 and have since then been on a massive decline reaching 8.2 GWp in 2015.
- With the introduction of new national tender schemes the LCOE of PV projects has dropped significantly. In the fourth tender in Germany in April 2014 the lowest bid reached down to 6.94 EUR cts/kWh.
- The PV installation capacity available under the tender scheme is limited and the size of projects has been capped at 10 MWp.

- The PV lending rate has been on a continuous decline in line with the interbanking rate EURIBOR since 2008.
- The decrease in project size and cost along with the overall drop of returns from capital markets has led to a slowdown of debt financing and an increasing share of 100% equity financed PV projects.

European PV installations are expected to stagnate in 2016 at around 8 GWp. At an estimated investment volume of approximately EUR 10 bn this represents less than 4% of the EUR 255 bn total renewable energy investments reported in “Global Trend in Renewable Energy Investments 2016” [37]. In most cases individual project finance volumes will not exceed EUR 10 million. Given the low rate of economically viable PV projects the new capital market regulations impose little to no barrier to the realisation of PV projects in Europe.

However, in order to meet the NREAP targets in 2020 and to reach the global warming target of less than 2°C established during COP21 in Paris in December 2016, much higher PV installation and funding rates will be required for Europe.

Under such a new PV investment cycle, the professional risk assessment methodology developed during the Solar Bankability project will help to enhance the transparency of technical risks and to provide suitable risk mitigation measures for future PV investments. Technical risk assessment of PV plants will gain even more importance as LCOEs continue their decline and become increasingly competitive. While the CAPEX continosly decreases the relative share of OPEX in the total life cycle costs increases over time due to the labour content and continuous wage increases.

6. Closing Remarks

The Solar Bankability project aims to establish a common practice for professional risk assessment which will serve to reduce the risks associated with investments in photovoltaic projects.

Since the start of the project several reports have already been published and can be downloaded free of charge from the project website www.solarbankability.eu :

- "PV Business Model Country Snapshots" provides an overview over existing and new PV business models and their roll-out in seven European countries.
- "Technical Risks in PV Projects" gives a comprehensive overview of technical risks of PV systems and introduces a systematic cost-based FMEA method to rank these risks using cost priority numbers.
- "Minimizing Technical Risks in Photovoltaik Projects" describes suitable risk mitigation measures and the impact of applied measures under different cost scenarios on the cost priority number.
- "Review and Gap Analysis of Technical Assumptions in PV Electricity Costs" introduces the concept of LCOE. The report summarises technical assumptions and provides a gap analysis influencing the calculation lifecycle costs including CAPEX, OPEX and Yield.

Till the end of the Solar Bankabiltiy project in February 2017 two more reports will be published and project result will be disseminated through a second public workshop early February 2017:

- "Best Practice Guidelines for PV Cost Calculation" explains how to account for technical risks in LCOE, CAPEX, OPEX and Yield calculations and how to minimize their impact for different PV business models.
- "Technical Bankability Guidelines" describes to stakeholders in PV investments, i.e. investors, banks, insurances, EPCs and component manufacturers how to identify potential technical risks, address risk liabilities, plan mititation measures and make tailored financial provisions.

The current report introduces a methodology to determine the financial impact of technical failures and presents a modelling tool to assess the impact of technical failures on the overall financial performance of four representative PV business models. A list of suitable risk mitigation measures for each business model is proposed. New financial market regulations and their impact on PV investments are introduced in a short overview.

The top 10 takeaways of this report are summarized in table 23.

Table 23: Top 10 takeaways for PV stakeholders from risk modelling exercise

1. PV investments are considered as qualified infrastructure investment. Compared with other asset classes PV projects offers a favourable risk profile. Under Solvency II the corresponding equity stress factor has been lowered accordingly.
2. New capital market regulations require a thorough due diligence and ongoing risk management procedures. Banks and insurances are requested to either implement a qualified inhouse risk rating or to take advantage of external professional rating services.
3. Most rating schemes for PV projects are compost of several risk categories. One of them are technical risks which represent up to 20% of the total rating scheme.
4. The impact of technical failures cannot be generalized. It depends on the individual framework conditions of the underlying PV business model , i.e. system size and design, geographic location, climate, technology, financing, taxation, jurisdiction and national policies.
5. The financial impact of technical failures beyond those already reflected by regular O&M provisions can be classified in four failure categories. Only categories 1 and 2 are covered by regular operations and maintenance provisions and reserve accounts. Failures in category 3 and 4 are more common in smaller than in larger PV systems. The financial impact of failures often depends to a large extend on high spare parts costs for modules and inverters,high downtime costs due to long detection and repair/substituion times and higher yield losses especially during the summer season.
6. PV investments require an enhanced risk awareness and active risk management. Since the financial crisis in 2008 the profitability of PV systems has decreased along the decline of overall financial market returns. Increased competition and cost pressure in the PV industry are threatening quality standards. Manufacturer and EPC insolvencies have made product warranties and performance guarantees become void.
7. A professional risk management plan should become integral part for each PV investment. The budget for risk assessment and mitigation measures should be adjusted to size and investment volume of the PV project. Mitigation measures should reflect the “bathtub” like curve of risk occurance and important milestones of system design, commisioning, end of warranty and guarantee periods. Ongoing monitoring and maintenance checks will help to minimize the occurance of failures.

8.	Manufacturers and EPC should use the risk assessment and modelling methodology and the risk data base developed under the Solar Bankability project and incorporate the lessons learnt into their component and system design. Rather than exchanging entire components, smart repair should become market standard i.e. to exchange defective module junction box diodes or inverter circuit boards. A PV system design based on. micro or string inverters sometimes might be less downtime prone than one based on central inverters.
9.	Banks and insurers should use the risk assessment and modelling methodology and the risk data base developed under the Solar Bankability project to optimize and adjust i.e. required debt service reserve accounts or to adjust insurance premiums according to the risk rating and age of the PV system
10.	To enhance the effectiveness of government tender schemes for large PV projects regulators should consider to include also non-monetary qualification requirements beyond the price-only criteria. A professional risk management plan to ensure the financial viability and technical reliability of the PV system should be incorporated. A quality monitoring program should accompany the tendering process. It should cover the project realization rate and a technical quality and performance check before the end of the PV system warranty period.

References

[1] Tjengdrawira,C., Richter,M., e.a., "Review and Gap Analysis of Technical Assumptions inn PV Electricity Cost", [Online] Available from: http://www.solarbankability.eu [Accessed: 19-Aug-2016]

[2] PVCalc, "The Return (ROI) Calculator for PV solar energy investments", [Online] Available from: http://www.pvcalc.org [Accessed: 27-Jul-2016]

[3] DGS Franken, "pv@now - Die Wirtschaftlichkeitssoftware für Photovoltaikanlagen", [Online] Available from: http://www.pv-now.de [Accessed: 27-Jul-2016]

[4] BSW Solar, "PV Power Invest", [Online] Available from: http://www.pvcalc.org [Accessed: 27-Jul-2016]

[5] Valentin-Software, "PV*SOL® - Dynamisches Simulationsprogramm zur Auslegung und Optimierung von Photovoltaikanlagen", [Online] Available from: http://www.valentin-software.com [Accessed: 27-Jul-2016]

[6] PVsyst, "Photovoltaic Software", [Online] Available from: http://www.pvsyst.com [Accessed: 27-Jul-2016]

[7] SMA, "Sunny Design Web - PV-Anlagen konfigurieren", [Online] Available from: http://www.sma.de/produkte/planungssoftware/sunny-design-web.html [Accessed: 27-Jul-2016]

[8] Moser,D., Del Buono, M., e.a., "Technical risks in PV projects", [Online] Available from: http://www.solarbankability.eu [Accessed: 19-Aug-2016], pp73

[9] Armansperg, M., Oechslin, D., Schweneke, M., “PV Business Model Country Snapshots”, [Online] Available from: http://www.solarbankability.eu [Accessed: 19-Aug-2016]

[10] EC Joint Research Center, “Photovoltaic Calculator for Europe”, [Online] Available from: http://photovoltaic-software.com/pvgis.php [Accessed: 01-Jun-2016]

[11] Jahn,U., Moser,D., e.a., "Minimizing Technical Risks in Photovoltaic Projects", [Online] Available from: http://www.solarbankability.eu [Accessed: 01-Sep-2016]

[12] Tjengdrawira, C., Richter, M., “Best Practice Guide for PV Cost Calculation”, [Online] Available from: http://www.solarbankability.eu [Publishing date 31-Oct-2016]

[13] Basel Committee on Banking Supervision, "Basel III Summary Table," [Online] Available from: http://www.bis.org/bcbs/basel3/b3summarytable.pdf [Accessed: 22 July 2016]

[14] Basel Committee on Banking Supervision, "Basel III: A global regulatory framework for more resilient banks and banking systems," Basel, Bank for International Settlement, 2010

[15] Basel Committee on Banking Supervision, "Basel III: A global regulatory framework for more resilient banks and banking systems," Basel, Bank for International Settlement, 2010 (rev June 2011)

[16] Basel Committee on Banking Supervision, "Basel III: The Liquidity Coverage Ratio and liquidity risk monitoring tools," Basel, Bank for International Settlement, 2013

[17] Basel Committee on Banking Supervision, "Basel III: The Net Stable Funding Ratio," Basel, Bank for International Settlement, 2014

[18] EC Fact Sheet, "Capital Requirements - CRD IV/CRR - Frequently Asked Questions," Brussels, European Commission, 2013, Memo/13/690

[19] Official Journal of the European Union, "Directive 2013/36/EU of the European Parliament and of the Council", Brussels, European Union, 2013

[20] Official Journal of the European Union, "Regulation (EU) No 575/2013 of the European Parliament and of the Council", Brussels, European Union, 2013

[21] Narbel, P., "The likely impact of Basel III on bank's appetite for renewable energy financing", Bergen, Norwegion School of Economics, 2013

[22] Donner,R., Berckmann C., Sabatelle A., "Rating Methodoloty - Power Generation Projects", New York, Moody's Investors Service, 2012

[23] Beauchemin, E., Widemann, K., "Methodology - Rating Solar Power Projects," Toronto, DBRS, 2012

[24] EC Fact Sheet, "Solveny II Overview - Frequently Asked Questions," Brussels, European Commission, 2015, Memo/15/3120

[25] Official Journal of the European Union, "Directive 2009/138/EC of the European Parliament and of the Council", Brussels, European Union, 2009

[26] Official Journal of the European Union, "Directive 2014/51/EU of the European Parliament and of the Council", Brussels, European Union, 2014

[27] European Insurance and Occuational Pensions Authority, "The underlying assumptions in the standard formula for the Solvency Capital Requirement calculation," Frankfurt, EIOPA, 2014

[28] EC Fact Sheet, "New EU rules to promote investments in infrastructure projects," Brussels, European Commission, 2015, Memo/15/5734

[29] Nelson, D., Pierpont, B., "The Challenge of Institutional Investment in Renewable Energy", San Francisco, Climate Policy Initiative, 2013

[30] EC Communication, "Action Plan on Building a Capital Markets Union", Brussels, European Commission, 2015, COM (2015) 468 final

[31] European Insurance and Occuational Pensions Authority, "Final Report on Consultation Paper no. 15/004 on the Call for Advice from the EC on the identificationn and calibration of infrastructure investment categories," Frankfurt, EIOPA, 2015

[32] Official Journal of the European Union, "Directive 2009/65/EU of the European Parliament and of the Council", Brussels, European Union, 2009

[33] Official Journal of the European Union, "Directive 2014/91/EU of the European Parliament and of the Council", Brussels, European Union, 2014

[34] Official Journal of the European Union, "Directive 2011/61/EU of the European Parliament and of the Council", Brussels, European Union, 2011

[35] EC Memo, "Directive on Alternative Investment Fund Managers ('AIFMD)': FAQs," Brussels, European Commission, 2010, Memo/10/572

[36] Noothout,P., de Jager, D., Tesniere, L., e.a., "The impact of risks in renewable energy investmetns and the role of smart policies, Freiburg, Fraunhofer ISI, 2016, (DiaCore Project)

[37] Frankfurt School-UNEP Centre/BNEF, “Global Trends in Renewable Energy Investments 2016”, [Online] Available from: http://fs-unep-centre.org/publications/global-trends-renewable-energy-investment-2016 [Accessed: 29-Sep-2016]

Appenidx A – Business Model Description

Business model 1[1)]		
Base parameters	**Unit**	**Value**
System type		Residential, roof-mounted
Nominal capacity	kWp	5.64
Project start	Date	January 1, 2011
Project duration	Years	20
System components	**Unit**	**Value**
Module type	Name	Yingli 235P
Inverter type	Name	SMA SB5000TL
Mounting table / tracker type.	Name	Creotecc RL Alutec
System design	**Unit**	**Value**
Number of modules	Parts	24
Number of modules per string	Parts	12
Module degradation	%/a	0.5
Number of inverters	Parts	1
Number of strings per inverter	Parts	2
Mounting table / tracker	Parts	1
Irradiation/yield	**Unit**	**Value**
Geographic location		Palatinate, Germany
Azimuth direction of PV system	Degree	-10
Tilt angle of modules	Degree	34
Global tilted irradiation (GTI) [2)]	kWh/m2/a	1264
Performance Ratio [2)]	%/a	80.40
Financial parameter	**Unit**	**Value**
Equity Financing [3)]	%	100
Capital expenditures (CAPEX)	EUR	Confidential
Depreciation	Years	20
Operational expenditures (OPEX) [4)]	EUR/a	Confidential
Inflation	%/a	2.00
Electricity feed-in tariff	EUR/kWh	0.2874
Regular contract duration of electricity tariff	Years	20
Comments		
[1)] Source of information: ACCELIOS Solar		
[2)] Values calculated with PVGIS		
[3)] For technical risk modelling purposes only		
[4)] Without regular maintenance, including cost for central inverter overhaul after 10 years		

Business model 2[1)]		
Base parameters	**Unit**	**Value**
System type		Residential, roof-mounted
Nominal capacity	kWp	5.2
Project start	Date	January 1, 2015
Project duration	Years	20
System components	**Unit**	**Value**
Module type	Name	Aleo S79 L260
Inverter type	Name	SMA SB2.5 1VL40
Mounting table / tracker type.	Name	K2
Battery Inverter	Name	SMA SB Storage 2.5
Storage Battery	Name	IBC Solstore 2.5
System design	**Unit**	**Value**
Number of modules	Parts	20
Number of modules per string	Parts	10
Module degradation	%/a	0.5
Number of inverters	Parts	1
Number of strings per inverter	Parts	2
Irradiation/yield	**Unit**	**Value**
Geographic location		Bavaria, Germany
Azimuth direction of PV system	Degree	0
Tilt angle of modules	Degree	24
Global tilted irradiation (GTI) [2)]	kWh/m2/a	1260
Performance Ratio [2)]	%	80.40
Financial parameter	**Unit**	**Value**
Equity Financing [3)]	%	100
Capital expenditures (CAPEX)	EUR	Confidential
Depreciation	Years	20
Operational expenditures (OPEX) [4)]	EUR/a	Confidential
Inflation	%/a	2.00
Electricity feed-in tariff	EUR/kWh	0.1231
Regular contract duration of electricity tariff	Years	20
Self-consumption tariff	EUR/kWh	0.2792
Share of self-consumption	%	58.10
Comments		

[1)] Source of information: DGS Franken

[2)] Values calculated with PVGIS

[3)] For technical risk modelling purposes only

[4)] Including annual maintenance and inverter exchange and battery overhaul after 10 years

Business model 3[1)]

Base parameters	Unit	Value
System type		Utility, ground mounted
Nominal capacity	kWp	7619
Project start	Date	January 1, 2011
Project duration	Years	20
System components	**Unit**	**Value**
Module type	Name	Q CELLS Q.Pro-G3 260
Inverter type	Name	SMA SC800CP-XT
Mounting table / tracker type.	Name	CWF
System design	**Unit**	**Value**
Number of modules	Parts	29304
Number of modules per string	Parts	22
Module degradation	%/a	0.5
Number of inverters	Parts	7
Number of strings per inverter	Parts	190
Mounting table / tracker	Parts	333
Irradiation/yield	**Unit**	**Value**
Geographic location		Nottinghamshire, UK
Azimuth direction of PV system	Degree	0
Tilt angle of modules	Degree	25
Global tilted irradiation (GTI)[2)]	kWh/m2/a	1195
Performance Ratio 2[)]	%	80.78
Financial parameter	**Unit**	**Value**
Equity Financing[3)]	%	100
Capital expenditures (CAPEX)	EUR	Confidential
Depreciation	Years	20
Operational expenditures (OPEX)[4)]	EUR/a	Confidential
Inflation	%/a	2.00
Electricity feed-in tariff[5)]	EUR/kWh	0.560
Regular contract duration of electricity tariff	Years	20
Exchange rate	GBP/EUR	1.27807

Comments

[1)] Source of Information: Solarcentury

[2)] Values calculated with PVGIS

[3)] For technical risk modelling purposes only

[4)] Including cost for central inverter overhaul after 10 years

[5)] Feed-in tariff based on ROCs

Business model 4[1)]		
Base parameters	**Unit**	**Value**
System type		Utility, ground mounted
Nominal capacity	kWp	662.60
Project start	Date	July 1, 2010
Project duration	Years	20
System components	**Unit**	**Value**
Module type	Name	First Solar FS277
Inverter type[2)]	Name	SMA SMC7000, 8000, 9000
Mounting table / tracker type.	Name	Schletter
System design	**Unit**	**Value**
Number of modules	Parts	8542
Number of modules per string	Parts	10
Module degradation	%/a	0.5
Number of inverters	Parts	75
Number of strings per inverter	Parts	12
Mounting table / tracker	Parts	125
Irradiation/yield	**Unit**	**Value**
Geographic location		South Tyrol, Italy
Azimuth direction of PV system	Degree	-9
Tilt angle of modules	Degree	30
Global tilted irradiation (GTI)[3)]	kWh/m2/a	1675
Performance Ratio[3)]	%	87.00
Financial parameter	**Unit**	**Value**
Equity Financing[4)]	%	100
Capital expenditures (CAPEX)	EUR	Confidential
Depreciation	Years	20
Operational expenditures (OPEX)[5)]	EUR/a	Confidential
Inflation	%/a	2.00
Electricity feed-in tariff	EUR/kWh	0.3600
Regular contract duration of electricity tariff	Years	20
Comments		

[1)] Source of Information: EURAC

[2)] Mix of three string inverter sizes

[3)] Values calculated with PVGIS

[4)] For technical risk modelling purposes only

[5)] Including cost for central inverter overhaul after 10 years

APPENDIX B – Risk Database

Business model 1 - risk database

			Severity		Duration				Start
Risk number	Name of risk	Case	Number of components with failures = n (comp, fail)	Multiplier for failure effect on higher system level m	Detection time (d) = t (detect) (days)	Set-up time (d) = t (rep/sup)+t (transp) (days)	Repair time (d) = t (fix) (days)	Total Risk Duration (days)	Risk Start Date (DD.MM.YYYY)
1000	PID = Potential Induced degradation	Best	2.00	12.00	90.00	14.00	0.04	104.04	01.01.2011
1001	PID = Potential Induced degradation	Worst	24.00	24.00	730.00	14.00	0.50	744.50	01.01.2011
1010	Failure of bypass diode and juction box	Best	2.00	12.00	90.00	14.00	0.04	104.04	01.10.2021
1011	Failure of bypass diode and juction box	Worst	24.00	24.00	730.00	14.00	0.50	744.50	01.10.2021
1020	Hotspot of modules	Best	2.00	12.00	90.00	14.00	0.04	104.04	01.04.2019
1021	Hotspot of modules	Worst	24.00	24.00	730.00	14.00	0.50	744.50	01.04.2019
1030	Theft/ vandalism of modules	Best	12.00	12.00	1.00	14.00	0.25	15.25	01.02.2013
1031	Theft/ vandalism of modules	Worst	24.00	24.00	7.00	14.00	0.50	21.50	01.02.2013
1040	Fan failure and overheating	Best	1.00	24.00	90.00	14.00	0.04	104.04	01.08.2016
1041	Fan failure and overheating	Worst	1.00	24.00	730.00	14.00	0.04	744.04	01.08.2016
1050	Lightning strike of inverter	Best	1.00	12.00	1.00	14.00	0.04	15.04	01.06.2026
1051	Lightning strike of inverter	Worst	1.00	24.00	7.00	14.00	0.04	21.04	01.06.2026
1060	Mismatch of module clamps	Best	4.00	12.00	365.00	14.00	0.02	379.02	01.01.2011
1061	Mismatch of module clamps	Worst	48.00	24.00	730.00	14.00	0.02	744.20	01.01.2011
1070	UV aging of string cables	Best	1.00	24.00	365.00	14.00	0.08	379.02	01.07.2026
1071	UV aging of string cables	Worst	2.00	24.00	730.00	14.00	0.17	744.17	01.07.2026
1080	Wrong/Absent cables connection	Best	1.00	12.00	365.00	14.00	0.02	379.02	01.01.2011
1081	Wrong/Absent cables connection	Worst	2.00	24.00	730.00	14.00	0.04	744.04	01.01.2011
1090	Cabling damaged by rodents	Best	2.00	24.00	365.00	14.00	0.04	379.04	01.05.2014
1091	Cabling damaged by rodents	Worst	24.00	24.00	730.00	14.00	0.50	744.50	01.05.2014
1100	Module breakage by hail	Best	2.00	12.00	1.00	14.00	0.41	15.04	01.08.2017
1101	Module breakage by hail	Worst	24.00	24.00	90.00	14.00	0.25	104.25	01.08.2017
1110	Soiling of modules	Best	2.00	12.00	365.00	14.00	0.01	379.01	01.03.2014
1111	Soiling of modules	Worst	24.00	24.00	730.00	14.00	0.10	744.10	01.03.2014

	Performance loss				Fixing costs				
Risk number	Performance loss PL1 during t(det/rep/sup)	Performance loss PL2 during t(fix)	Battery Storage loss SL1 during t(det/rep/sub)	Battery Storage loss SL2 during t(fix)	Detecion costs = C (detect) (EUR)	Repair/substitution costs = C (rep/sub) (EUR)	Transportation costs = C (transp) (EUR)	Labor costs = C (lab) EUR)	Total fixing costs (EUR)
1000	0.10	1.00	n.a.	n.a.	80.00	400.00	125.00	100.00	705.00
1001	0.50	1.00	n.a.	n.a.	120.00	4800.00	375.00	540.00	5835.00
1010	0.33	1.00	n.a.	n.a.	80.00	400.00	125.00	100.00	705.00
1011	0.33	1.00	n.a.	n.a.	120.00	4800.00	1075.00	540.00	6535.00
1020	0.20	1.00	n.a.	n.a.	80.00	400.00	125.00	100.00	705.00
1021	0.50	1.00	n.a.	n.a.	120.00	4800.00	1075.00	540.00	6535.00
1030	0.50	1.00	n.a.	n.a.	80.00	2400.00	125.00	300.00	2905.00
1031	1.00	1.00	n.a.	n.a.	80.00	4800.00	1075.00	540.00	6495.00
1040	0.20	1.00	n.a.	n.a.	80.00	200.00	125.00	110.00	515.00
1041	0.50	1.00	n.a.	n.a.	120.00	1325.00	125.00	110.00	1680.00
1050	1.00	1.00	n.a.	n.a.	80.00	1325.00	125.00	110.00	1640.00
1051	1.00	1.00	n.a.	n.a.	120.00	1325.00	125. 00	110.00	1680.00
1060	0.00	1.00	n.a.	n.a.	80.00	12.00	12.50	74.00	178.50
1061	0.00	1.00	n.a.	n.a.	120.00	144.00	37.50	368.00	669.50
1070	0.10	1.00	n.a.	n.a.	80.00	15.72	37.50	200.00	333.22
1071	0.30	1.00	n.a.	n.a.	120.00	31.44	37.50	320.00	508.94
1080	0.10	1.00	n.a.	n.a.	80.00	3.00	12.50	110.00	205.50
1081	0.30	1.00	n.a.	n.a.	120.00	6.00	12.50	140.00	278.50
1090	0.10	1.00	n.a.	n.a.	120.00	6.00	12.50	80.00	218.50
1091	0.30	1.00	n.a.	n.a.	200.00	1017.60	1075.00	500.00	2792.60
1100	0.20	1.00	n.a.	n.a.	80.00	400.00	125.00	100.00	705.00
1101	0.50	1.00	n.a.	n.a.	120.00	4800.00	1075.00	540.00	6535.00
1110	0.10	1.00	n.a.	n.a.	80.00	0.00	0.00	80.00	160.00
1111	0.30	1.00	n.a.	n.a.	80.00	0.00	700.00	156.00	936.00

Business model 2 - risk database

			Severity		Duration				Start
Risk number	Name of risk	Case	Number of components with failures = n (comp, fail)	Multiplier for failure effect on higher system level m	Detection time (d) = t (detect) (days)	Set-up time (d) = t (rep/sup)+t (transp) (days)	Repair time (d) = t (fix) (days)	Total Risk Duration (days)	Risk Start Date (DD.MM.YYYY)
2000	PID = Potential Induced degradation	Best	2.00	10.00	90.00	14.00	0.04	104.04	01.01.2015
2001	PID = Potential Induced degradation	Worst	20.00	20.00	730.00	14.00	0.42	744.42	01.01.2015
2010	Failure of bypass diode and juction box	Best	2.00	10.00	90.00	14.00	0.04	104.04	01.10.2025
2011	Failure of bypass diode and juction box	Worst	20.00	20.00	730.00	14.00	0.42	744.42	01.10.2025
2020	Hotspot of modules	Best	2.00	10.00	90.00	14.00	0.04	104.04	01.04.2023
2021	Hotspot of modules	Worst	20.00	20.00	730.00	14.00	0.42	744.42	01.04.2023
2030	Theft/ vandalism of modules	Best	10.00	10.00	1.00	14.00	0.20	15.21	01.02.2017
2031	Theft/ vandalism of modules	Worst	20.00	20.00	7.00	14.00	0.42	21.42	01.02.2017
2040	Fan failure and overheating	Best	1.00	10.00	90.00	14.00	0.04	104.04	01.08.2020
2041	Fan failure and overheating	Worst	2.00	20.00	730.00	14.00	0.08	744.08	01.08.2020
2050	Lightning strike of inverter	Best	1.00	10.00	1.00	14.00	0.04	42475	01.06.2032
2051	Lightning strike of inverter	Worst	2.00	20.00	7.00	14.00	0.08	42603	01.06.2032
2060	Mismatch of module clamps	Best	4.00	10.00	365.00	14.00	0.02	379.02	01.01.2015
2061	Mismatch of module clamps	Worst	40.00	20.00	730.00	14.00	0.17	744.17	01.01.2015
2070	UV aging of string cables	Best	1.00	10.00	365.00	14.00	0.08	379.08	01.07.2030
2071	UV aging of string cables	Worst	2.00	20.00	730.00	14.00	0.17	744.17	01.07.2030
2080	Wrong/Absent cables connection	Best	1.00	10.00	365.00	14.00	0.02	379.02	01.01.2015
2081	Wrong/Absent cables connection	Worst	2.00	20.00	730.00	14.00	0.04	744.04	01.01.2015
2090	Cabling damaged by rodents	Best	2.00	10.00	365.00	14.00	0.04	379.04	01.05.2018
2091	Cabling damaged by rodents	Worst	20.00	20.00	730.00	14.00	0.42	744.42	01.05.2018
2100	Failure of battery	Best	1.00	0.00	90.00	14.00	0.08	74.08	01.07.2021
2101	Failure of battery	Worst	1.00	0.00	730.00	14.00	0.08	42597	01.07.2021
2110	Failure of battery inververter	Best	1.00	0.00	90.00	14.00	0.04	74.04	01.04.2018
2111	Failure of battery inververter	Worst	1.00	0.00	730.00	14.00	0.04	744.04	01.04.2018

	Performance loss				Fixing costs				
Risk number	Performance loss PL1 during t(det/rep/sup)	Performance loss PL2 during t(fix)	Battery Storage loss SL1 during t(det/rep/sub)	Battery Storage loss SL2 during t(fix)	Detecion costs = C (detect) (EUR)	Repair/substitution costs = C (rep/sub) (EUR)	Transportation costs = c (transp) (EUR)	Labor costs = c (lab) EUR)	Total fixing costs (EUR)
2000	0.10	1.00	n.a.	n.a.	80.00	520.00	125.00	100.00	825.00
2001	0.50	1.00	n.a.	n.a.	120.00	5200.00	1075.00	460.00	6855.00
2010	0.33	1.00	n.a.	n.a.	80.00	520.00	125.00	100.00	825.00
2011	0.33	1.00	n.a.	n.a.	120.00	5200.00	1075.00	460.00	6855.00
2020	0.20	1.00	n.a.	n.a.	80.00	520.00	125.00	100.00	825.00
2021	0.50	1.00	n.a.	n.a.	120.00	5200.00	1075.00	460.00	6855.00
2030	0.50	1.00	n.a.	n.a.	80.00	2600.00	125.00	260.00	3065.00
2031	1.00	1.00	n.a.	n.a.	80.00	5200.00	125.00	460.00	5865.00
2040	0.20	1.00	n.a.	n.a.	80.00	260.00	125.00	110.00	575.00
2041	0.50	1.00	n.a.	n.a.	120.00	980.00	125.00	170.00	1395.00
2050	1.00	1.00	n.a.	n.a.	80.00	1960.00	12.50	110.00	2162.50
2051	1.00	1.00	n.a.	n.a.	120.00	980.00	37.50	170.00	1307.50
2060	0.00	1.00	n.a.	n.a.	80.00	12.00	37.50	74.00	203.0
2061	0.00	1.00	n.a.	n.a.	120.00	120.00	37.50	320.00	597.50
2070	0.10	1.00	n.a.	n.a.	80.00	15.72	12.50	200.00	308.22
2071	0.30	1.00	n.a.	n.a.	120.00	31.44	12.50	320.00	483.94
2080	0.10	1.00	n.a.	n.a.	80.00	3.00	12.50	110.00	205.50
2081	0.30	1.00	n.a.	n.a.	120.00	6.00	1075.00	140.00	1341.00
2090	0.10	1.00	n.a.	n.a.	120.00	6.00	125.00	80.00	331.00
2091	0.10	1.00	n.a.	n.a.	200.00	1088.00	1075.00	420.00	2783.00
2100	0.00	1.00	0.30	1.00	80.00	2168.07	375.00	200.00	1855.00
2101	0.00	1.00	1.00	1.00	80.00	7226.89	375.00	200.00	4655.00
2110	0.00	1.00	0.30	1.00	80.00	0.00	0.00	140.00	220.00
2111	0.00	1.00	1.00	1.00	80.00	1025.21	125.00	140.00	1545.00

Business model 3 - risk database

			Severity		Duration				Start
Risk number	Name of risk	Case	Number of components with failures = n (comp, fail)	Multiplier for failure effect on higher system level m	Detection time (d) = t (detect) (days)	Set-up time (d) = t (rep/sup)+t (transp) (days)	Repair time (d) = t (fix) (days)	Total Risk Duration (days)	Risk Start Date (DD.MM.YYYY)
3000	PID = Potential Induced degradation	Best	1465.20	1474.00	182.50	14.00	5.00	201.50	01.01.2011
3001	PID = Potential Induced degradation	Worst	8791.20	29304.00	365.00	31.00	20.00	416.00	01.01.2011
3010	Failure of bypass diode and juction box	Best	1465.20	1474.00	91.25	14.00	5.00	110.25	01.10.2021
3011	Failure of bypass diode and juction box	Worst	8791.20	29304,00	365.00	31.00	20.00	416.00	01.10.2021
3020	Hotspot of modules	Best	1465.20	1474.00	182.50	14.00	5.00	201.50	01.04.2019
3021	Hotspot of modules	Worst	8791.20	29304.00	365.00	31.00	20.00	416.00	01.04.2019
3030	Theft/ vandalism of modules	Best	50.00	66.00	1.00	14.00	1.00	16.00	01.02.2013
3031	Theft/ vandalism of modules	Worst	500.00	8360.00	31.00	14.00	3.25	48.25	01.02.2013
3040	Fan failure and overheating	Best	1.00	4180.00	1.00	14.00	0.50	15.50	01.08.2016
3041	Fan failure and overheating	Worst	3.00	12540.00	31.00	31.00	2.00	64.00	01.08.2016
3050	Lightning strike of inverter	Best	1.00	4180.00	1.00	31.00	1.00	33.00	01.06.2026
3051	Lightning strike of inverter	Worst	3.00	12540.00	31.00	31.00	3.00	65.00	01.06.2026
3060	Mismatch of module clamps	Best	5860.80	2948.00	365.00	14.00	5.00	384.00	01.01.2011
3061	Mismatch of module clamps	Worst	17582.40	29304.00	365.00	31.00	10.00	406.00	01.01.2011
3070	UV aging of string cables	Best	133.00	2926.00	182.50	14.00	5.00	201.50	01.07.2026
3071	UV aging of string cables	Worst	399.00	12540.00	365.00	31.00	14.00	430.00	01.07.2026
3080	Wrong/Absent cables connection	Best	133.00	2926.00	91.25	14.00	2.00	107.25	01.01.2011
3081	Wrong/Absent cables connection	Worst	399.00	12540.00	730.00	31.00	10.00	771.00	01.01.2011
3090	Cabling damaged by rodents	Best	1465.20	1474.00	91.25	14.00	5.00	115.25	01.05.2014
3091	Cabling damaged by rodents	Worst	2930.40	29304.00	365.00	31.00	10.00	406.00	01.05.2014
3100	Flooding of inverter	Best	1.00	4180.00	1.00	31.00	1.00	33.00	01.08.2017
3101	Flooding of inverter	Worst	3.00	12540.00	31.00	31.00	3.00	65.00	01.08.2017
3110	Soiling of modules	Best	2930.00	2930.00	365.00	14.00	3.00	382.00	01.03.2014
3111	Soiling of modules	Worst	29304.00	29304.00	730.00	31.00	20.00	781.00	01.03.2014

	Performance loss				Fixing costs				
Risk number	Performance loss PL1 during t(det/rep/sup)	Performance loss PL2 during t(fix)	Battery Storage loss SL1 during t(det/rep/sub)	Battery Storage loss SL2 during t(fix)	Detecion costs = C (detect) (EUR)	Repair/substitution costs = C (rep/sub) (EUR)	Transportation costs = c (transp) (EUR)	Labor costs = c (lab) EUR)	Total fixing costs (EUR)
3000	0.10	1.00	n.a.	n.a.	1460.00	274285.44	6000.00	19652.00	301397.44
3001	0.70	1.00	n.a.	n.a.	3910.00	1645712.64	33000.00	117912.00	1800534.64
3010	0.33	1.00	n.a.	n.a.	1460.00	274285.44	6000.00	19652.00	301397.44
3011	0.33	1.00	n.a.	n.a.	3910.00	1645712.64	33000.00	11791200	1800534.64
3020	0.20	1.00	n.a.	n.a.	1460.00	274285.44	6000.00	19652.00	301397.44
3021	0.50	1.00	n.a.	n.a.	3910.00	1645712.64	33000.00	117912.00	1800534.64
3030	1.00	1.00	n.a.	n.a.	500.00	9360.00	300.00	840.00	11000.00
3031	1.00	1.00	n.a.	n.a.	2790.00	93600.00	3240.00	7020.00	106650.00
3040	0.20	1.00	n.a.	n.a.	500.00	2779.20	100.00	1850.00	5229.20
3041	0.50	1.00	n.a.	n.a.	2790.00	8337.60	375.00	2946.85	14449.45
3050	1.00	1.00	n.a.	n.a.	500.00	62472.00	1440.00	2650.00	67062.00
3051	1.00	1.00	n.a.	n.a.	2790.00	187416.00	4320.00	5690.00	200216.00
3060	0.00	1.00	n.a.	n.a.	740.00	14065.92	300.00	10236.25	25342.17
3061	0.00	1.00	n.a.	n.a.	3910.00	42197.76	300.00	30608.76	77016.53
3070	0.10	1.00	n.a.	n.a.	500.00	4309.20	300.00	7220.00	12329.20
3071	0.30	1.00	n.a.	n.a.	2790.00	12927.60	600.00	21600.00	37917.60
3080	0.10	1.00	n.a.	n.a.	500.00	319.20	100.00	1910.00	2829.20
3081	0.30	1.00	n.a.	n.a.	2790.00	957.60	100.00	4775.00	8622.60
3090	0.10	1.00	n.a.	n.a.	1460.00	57670.27	6600.00	19652.00	85382.27
3091	0.30	1.00	n.a.	n.a.	2790.00	115340.54	6600.00	39304.00	164034.54
3100	1.00	1.00	n.a.	n.a.	500.00	62472.00	1440.00	2650.00	67062.00
3101	1.00	1.00	n.a.	n.a.	2790.00	187416.00	4320.00	6330.00	200856.00
3110	0.10	0.00	n.a.	n.a.	500.00	0.00	0.00	1659.00	2159.00
3111	0.30	0.00	n.a.	n.a.	1790.00	0.00	0.00	12871.20	14661.20

Business model 4 - risk database

			Severity		Duration				Start
Risk number	Name of risk	Case	Number of components with failures = n (comp, fail)	Multiplier for failure effect on higher system level m	Detection time (d) = t (detect) (days)	Set-up time (d) = t (rep/sup)+t (transp) (days)	Repair time (d) = t (fix) (days)	Total Risk Duration (days)	Risk Start Date (DD.MM.YYYY)
4000	Low power/TCO corrosion of modules	Best	427.10	430.00	182.50	14.00	5.00	201.50	01.07.2010
4001	Low power/TCO corrosion of modules	Worst	2562.60	8542.00	365.00	31.00	9.00	405.00	01.07.2010
4010	Failure of bypass diode and juction box	Best	427.10	430.00	91.25	14.00	5.00	110.25	01.10.2020
4011	Failure of bypass diode and juction box	Worst	2562.60	8542.00	365.00	31.00	9.00	405.00	01.10.2020
4020	Hotspot of modules	Best	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
4021	Hotspot of modules	Worst	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
4030	Theft/ vandalism of modules	Best	50.00	50.00	1.00	14.00	1.00	16.00	01.02.2012
4031	Theft/ vandalism of modules	Worst	500.00	1000.00	31.00	14.00	5.00	50.00	01.02.2012
4040	Fan failure and overheating	Best	4.00	480.00	1.00	14.00	0.40	15.40	01.08.2015
4041	Fan failure and overheating	Worst	23.00	2760.00	31.00	31.00	1.00	63.00	01.08.2015
4050	Lightning strike of inverter	Best	4.00	480.00	1.00	14.00	0.40	15.40	01.06.2025
4051	Lightning strike of inverter	Worst	23.00	1080.00	31.00	14.00	1.00	46.00	01.06.2025
4060	Mismatch of module clamps	Best	854.20	427.10	365.00	14.00	2.00	381.00	01.07.2010
4061	Mismatch of module clamps	Worst	5125.20	2562.60	365.00	31.00	5.00	401.00	01.07.2010
4070	UV aging of string cables	Best	45.00	450.00	182.50	14.00	2.50	199.00	01.07.2025
4071	UV aging of string cables	Worst	270.00	2700.00	365.00	31.00	5.00	421.00	01.07.2025
4080	Wrong/Absent cables connection	Best	45.00	450.00	91.25	14.00	1.00	106.25	01.07.2010
4081	Wrong/Absent cables connection	Worst	270.00	2700.00	730.00	31.00	4.00	765.00	01.07.2010
4090	Cabling damaged by rodents	Best	427.10	430.00	91.25	14.00	4.00	109.25	01.05.2013
4091	Cabling damaged by rodents	Worst	854.20	860.00	365.00	31.00	5.00	401.00	01.05.2013
4100	Glass breakage of module, frameless	Best	427.10	430.00	91.25	14.00	5.00	110.25	01.01.2011
4101	Glass breakage of module, frameless	Worst	2562.60	8542.00	182.50	31.00	9.00	222.50	01.01.2011

	Performance loss				Fixing costs				
Risk number	Performance loss PL1 during t(det/rep/sup)	Performance loss PL2 during t(fix)	Battery Storage loss SL1 during t(det/rep/sub)	Battery Storage loss SL2 during t(fix)	Detecion costs = C (detect) (EUR)	Repair/substitution costs = C (rep/sub) (EUR)	Transportation costs = c (transp) (EUR)	Labor costs = c (lab) EUR)	Total fixing costs (EUR)
4000	0.10	1.00	n.a.	n.a.	1460.00	27701.71	5000.00	5571.00	39732.71
4001	0.50	1.00	n.a.	n.a.	2790.00	166210.23	8720.00	34666.00	212386.23
4010	0.33	1.00	n.a.	n.a.	1460.00	27701.70	5000.00	5571.00	39732.70
4011	0.33	1.00	n.a.	n.a.	2790.00	166210.24	8720.00	34666.00	212386.23
4020	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
4021	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
4030	1.00	1.00	n.a.	n.a.	500.00	3243	700.00	840.00	5283.00
4031	1.00	1.00	n.a.	n.a.	2790.00	32430.00	5000.00	6900.00	47120.00
4040	0.20	1.00	n.a.	n.a.	500.00	3600.00	1000.00	428.75	5528.75
4041	0.50	1.00	n.a.	n.a.	2790.00	21600.00	3560.00	1432.50	29382.50
4050	1.00	1.00	n.a.	n.a.	500.00	3600.00	1000.00	428.75	5528.75
4051	1.00	1.00	n.a.	n.a.	2790.00	21600.00	3560.00	1432.50	29382.5
4060	0.00	1.00	n.a.	n.a.	500.00	2050.08	100.00	1707.54	4357.62
4061	0.00	1.00	n.a.	n.a.	2790.00	12300.48	300.00	9265.26	24655.74
4070	0.10	1.00	n.a.	n.a.	500.00	946.35	300.00	2620.00	4366.35
4071	0.30	1.00	n.a.	n.a.	2790.00	5678.10	600.00	14600.00	23668.10
4080	0.10	1.00	n.a.	n.a.	500.00	108.00	100.00	790.00	1498.00
4081	0.30	1.00	n.a.	n.a.	1790.00	648.00	100.00	3760.00	6298.00
4090	0.10	1.00	n.a.	n.a.	500.00	6360.37	2920.00	5811.00	15591.37
4091	0.30	1.00	n.a.	n.a.	2790.00	12720.74	4700.00	11742.00	31952.74
4100	0.10	1.00	n.a.	n.a.	1460.00	27701.70	5000.00	5571.00	39732.70
4101	0.50	1.00	n.a.	n.a.	2790.00	166210.24	8720.00	34666.00	212386.23

APPENDIX C – Single Risk Results

Business model 1 - single risk results

Financial ratios/ figures (base case)

Revenue (12M)	IRR	Cumulative cash flow
1597 EUR	13.58%	14742 EUR

Risk result table

Risk	Name of risk	Start date of failure	Total failure costs C_{fail} (EUR)	IRR (incl failure) (%)	Cumulative cash flow (incl failure) (EUR)	Relative revenue loss C_{fail}/R_{M12} (%)	Risk category
1000	PID = Potential Induced degradation	01.01.2011	722	12.16	14020	45	1
1001	PID = Potential Induced degradation	01.01.2011	7458	4.68	7283	467	4
1010	Failure of bypass diode and juction box	01.10.2021	711	13.20	14031	44	1
1011	Failure of bypass diode and juction box	01.10.2021	7485	9.14	7256	469	4
1020	Hotspot of modules	01.04.2019	772	12.98	13969	48	1
1021	Hotspot of modules	01.04.2019	8142	7.36	6600	519	4
1030	Theft / vandalism of modules	01.02.2013	2914	9.41	11827	182	3
1031	Theft / vandalism of modules	01.02.2013	6550	5.56	8192	410	4
1040	Fan failure and overheating	01.08.2016	607	12.90	14135	38	1
1041	Fan failure and overheating	01.08.2016	3301	10.47	11440	207	4
1050	Lightning strike of inverter	01.06.2026	1687	13.03	13054	106	3
1051	Lightning strike of inverter	01.06.2026	1812	12.98	12929	113	3
1060	Mismatch of module clamps	01.01.2011	179	13.25	14563	11	1
1061	Mismatch of module clamps	01.01.2011	670	12.52	14072	42	1
1070	UV aging of string cables	01.07.2026	492	13.44	14250	31	1
1071	UV aging of string cables	01.07.2026	1435	13.19	13307	90	2
1080	Wrong/Absent cables connection	01.01.2011	288	13.04	14454	18	1
1081	Wrong/Absent cables connection	01.01.2011	1252	11.40	13489	78	2
1090	Cabling damaged by rodents	01.05.2014	388	13.07	14353	24	1
1091	Cabling damaged by rodents	01.05.2014	3781	9.34	10961	237	4
1100	Module breakage by hail	01.08.2017	714	12.87	14027	45	1
1101	Module breakage by hail	01.08.2017	6764	6.87	7978	424	4
1110	Soiling of modules	01.03.2014	241	13.26	14501	15	1
1111	Soiling of modules	01.03.2014	1895	11.31	12847	60	3

Distribution of total failure costs

Risk	Failure detection costs C_{det} (EUR)	Component replacement/ substituion costs $C_{rep/sub}$ (EUR)	Tansport and site preparation costs C_{trans} (EUR)	Labor costs to fix failure C_{lab} (EUR)	Total fixing costs C_{fix} (EUR)	Total down time costs C_{down} (EUR)	Total failure costs C_{fail} (EUR)
1000	80	400	125	100	705	17	722
1001	120	4800	375	540	5835	1623	7458
1010	80	400	125	100	705	6	711
1011	120	4800	1075	540	6535	950	7485
1020	80	400	125	100	705	67	772
1021	120	4800	1075	540	6535	1607	8142
1030	80	2400	125	300	2905	9	2914
1031	80	4800	1075	540	6495	55	6550
1040	80	200	125	110	515	92	607
1041	120	1325	125	110	1680	1621	3301
1050	80	1325	125	110	1640	47	1687
1051	120	1325	125	110	1680	132	1812
1060	80	12	13	74	179	0	179
1061	120	144	38	368	670	0	670
1070	80	16	38	200	333	159	492
1071	120	31	38	320	509	926	1435
1080	80	3	13	110	206	82	288
1081	120	6	13	140	279	974	1252
1090	120	6	13	80	219	170	388
1091	200	1018	1075	500	2793	988	3781
1100	80	400	125	100	705	9	714
1101	120	4800	1075	540	6535	229	6764
1110	80	0	0	80	160	81	241
1111	80	0	700	156	936	959	1895

Business model 2 - single risk results

Financial ratios/ figures (base case)

Revenue (12M)	IRR	Cumulative cash flow
1126 EUR	0.20%	242 EUR

Risk result table

Risk	Name of risk	Start date of failure	Total failure costs C_{fail} (EUR)	IRR (incl failure) (%)	Cumulative cash flow (incl failure) (EUR)	Relative revenue loss C_{fail}/R_{M12} (%)	Risk category
2000	PID = Potential Induced degradation	01.01.2015	833	-0.47	-596	74	2
2001	PID = Potential Induced degradation	01.01.2015	7516	-4.81	-7763	668	4
2010	Failure of bypass diode and juction box	01.10.2025	828	-0.50	-588	4	2
2011	Failure of bypass diode and juction box	01.10.2025	7240	-8.94	-7277	643	4
2020	Hotspot of modules	01.04.2023	851	-0.52	-625	76	2
2021	Hotspot of modules	01.04.2023	7506	-7.62	-7739	667	4
2030	Theft / vandalism of modules	01.02.2017	3070	-2.07	-2831	273	4
2031	Theft / vandalism of modules	01.02.2017	5891	-3.78	-5670	523	4
2040	Fan failure and overheating	01.08.2020	593	-0.30	-365	53	2
2041	Fan failure and overheating	01.08.2020	2051	-1.87	-2293	82	3
2050	Lightning strike of inverter	01.06.2030	2181	-2.00	-1949	194	3
2051	Lightning strike of inverter	01.06.2030	1358	-1.07	-1147	121	3
2060	Mismatch of module clamps	01.01.2015	204	-0.03	39	18	1
2061	Mismatch of module clamps	01.01.2015	598	-0.28	-355	53	2
2070	UV aging of string cables	01.07.2030	340	-0.10	-122	30	1
2071	UV aging of string cables	01.07.2030	859	-0.81	-893	76	2
2080	Wrong/Absent cables connection	01.01.2015	239	-0.02	-22	21	1
2081	Wrong/Absent cables connection	01.01.2015	1738	-1.35	-1789	154	3
2090	Cabling damaged by rodents	01.05.2018	365	-0.12	-148	32	1
2091	Cabling damaged by rodents	01.05.2018	2916	-2.16	-2772	259	4
2100	Failure of battery	01.07.2021	1892	-1.33	-1650	168	3
2101	Failure of battery	01.07.2021	5600	-4.53	-5358	497	4
2110	Failure of battery inververter	01.07.2018	258	-0.01	-16	23	1
2111	Failure of battery inververter	01.07.2018	2506	-1.79	-2264	223	4

Distribution of total failure costs

Risk	Failure detection costs C_{det} (EUR)	Component replacement/ substituion costs $C_{rep/sub}$ (EUR)	Tansport and site preparation costs C_{trans} (EUR)	Labor costs to fix failure C_{lab} (EUR)	Total fixing costs C_{fix} (EUR)	Total down time costs C_{down} (EUR)	Total failure costs C_{fail} (EUR)
2000	80	520	125	100	825	8	833
2001	120	5200	1075	460	6855	661	7516
2010	80	520	125	100	825	3	828
2011	120	5200	1075	460	6855	385	7240
2020	80	520	125	100	825	26	851
2021	120	5200	1075	460	6855	651	7506
2030	80	2600	125	260	3065	5	3070
2031	80	5200	125	460	5865	26	5891
2040	80	260	125	110	575	18	593
2041	120	980	125	170	1395	656	2051
2050	80	1960	13	110	2163	18	2181
2051	120	980	38	170	1308	51	1358
2060	80	12	38	74	204	0	204
2061	120	120	38	320	598	0	598
2070	80	16	13	200	308	32	340
2071	120	31	13	320	484	375	859
2080	80	3	13	110	206	34	239
2081	120	6	1075	140	1341	397	1738
2090	120	6	125	80	331	34	365
2091	200	1088	1075	420	2783	133	2916
2100	80	1200	375	200	1855	37	1892
2101	80	4000	375	200	4655	945	5600
2110	80	0	0	140	220	38	258
2111	80	1200	125	140	1545	961	2506

Business model 3 - single risk results

Financial ratios/ figures (base case)

Revenue (12M)	IRR	Cumulative cash flow
1147022 EUR	5.52%	5579932 EUR

Risk result table

Risk	Name of risk	Start date of failure	Total failure costs C_{fail} (EUR)	IRR (incl failure) (%)	Cumulative cash flow (incl failure) (EUR)	Relative revenue loss C_{fail}/R_{M12} (%)	Risk category
3000	PID = Potential Induced degradation	01.01.2011	304994	5.10	5274938	27	1
3001	PID = Potential Induced degradation	01.01.2011	2434717	2.68	3145215	212	4
3010	Failure of bypass diode and juction box	01.10.2021	306053	5.27	5273879	27	1
3011	Failure of bypass diode and juction box	01.10.2021	2198632	3.63	3381300	192	3
3020	Hotspot of modules	01.04.2019	309495	5.24	5270437	27	1
3021	Hotspot of modules	01.04.2019	2476620	3.21	3103312	216	4
3030	Theft / vandalism of modules	01.02.2013	11078	5.51	5568854	1	1
3031	Theft / vandalism of modules	01.02.2013	136179	5.35	5443753	12	1
3040	Fan failure and overheating	01.08.2016	7104	5.51	5572828	1	1
3041	Fan failure and overheating	01.08.2016	68559	5.45	5511373	6	1
3050	Lightning strike of inverter	01.06.2026	87295	5.47	5492637	8	1
3051	Lightning strike of inverter	01.06.2026	314401	5.32	5265531	27	1
3060	Mismatch of module clamps	01.01.2011	25342	5.49	5554589	2	1
3061	Mismatch of module clamps	01.01.2011	77017	5.42	5502903	7	1
3070	UV aging of string cables	01.07.2026	17686	5.51	5562246	2	1
3071	UV aging of string cables	01.07.2026	199085	5.40	5380847	17	1
3080	Wrong/Absent cables connection	01.01.2011	5633	5.52	5574299	1	1
3081	Wrong/Absent cables connection	01.01.2011	316505	5.10	5263427	28	1
3090	Cabling damaged by rodents	01.05.2014	87821	5.42	5492112	8	1
3091	Cabling damaged by rodents	01.05.2014	565975	4.87	5013957	49	1
3100	Flooding of inverter	01.08.2017	86296	5.43	5493636	8	1
3101	Flooding of inverter	01.08.2017	309225	5.21	5270708	27	1
3110	Soiling of modules	01.03.2014	13920	5.51	5566013	1	1
3111	Soiling of modules	01.03.2014	752928	4.67	4827005	65	2

Distribution of total failure costs							
Risk	Failure detection costs C_{det} (EUR)	Component replacement/ substituion costs $C_{rep/sub}$ (EUR)	Tansport and site preparation costs C_{trans} (EUR)	Labor costs to fix failure C_{lab} (EUR)	Total fixing costs C_{fix} (EUR)	Total down time costs C_{down} (EUR)	Total failure costs C_{fail} (EUR)
3000	1460	274285	6000	19652	301397	3597	304994
3001	3910	1645713	33000	117912	1800535	634183	2434717
3010	1460	274285	6000	19652	301397	4656	306053
3011	3910	1645713	33000	117912	1800535	398097	2198632
3020	1460	274285	6000	19652	301397	8098	309495
3021	3910	1645713	33000	117912	1800535	676085	2476620
3030	500	9360	300	840	11000	78	11078
3031	2790	93600	3240	7020	106650	29529	136179
3040	500	2779	100	1850	5229	1875	7104
3041	2790	8338	375	2947	14449	54109	68559
3050	500	62472	1440	2650	67062	20233	87295
3051	2790	187416	4320	5690	200216	114185	314401
3060	740	14066	300	10236	25342	0	25342
3061	3910	42198	300	30609	77017	0	77017
3070	500	4309	300	7220	12329	5357	17686
3071	2790	12928	600	21600	37918	161168	199085
3080	500	319	100	1910	2829	2804	5633
3081	2790	958	100	4775	8623	307882	316505
3090	1460	57670	6600	19652	85382	2438	87821
3091	2790	115341	6600	39304	164035	401941	565975
3100	500	62472	1440	2650	67062	19234	86296
3101	2790	187416	4320	6330	200856	108369	309225
3110	500	0	0	1659	2159	11761	13920
3111	1790	0	0	12871	14661	738266	752928

Business model 4 - single risk results

Financial ratios/ figures (base case)

Revenue (12M)	IRR	Cumulative cash flow
346027 EUR	10.74%	3449957 EUR

Risk result table

Risk	Name of risk	Start date of failure	Total failure costs C_{fail} (EUR)	IRR (incl failure) (%)	Cumulative cash flow (incl failure) (EUR)	Relative revenue loss C_{fail}/R_{M12} (%)	Risk category
4000	Low performance/ TCO corrosion of CdTe modules	01.07.2010	40650	10.50	3377665	12	1
4001	Low performance/ TCO corrosion of CdTe modules	01.07.2010	413940	8.56	3004376	119	3
4010	Failure of bypass diode and juction box	01.10.2020	39990	10.65	3378325	12	1
4011	Failure of bypass diode and juction box	01.10.2020	313025	10.07	3105291	90	2
4020	Hotspot of modules	n.a.					
4021	Hotspot of modules	n.a.					
4030	Theft / vandalism of modules	01.02.2012	5358	10.70	3412958	2	1
4031	Theft / vandalism of modules	01.02.2012	51801	10.47	3366515	15	1
4040	Fan failure and overheating	01.08.2015	5735	10.71	3412580	2	1
4041	Fan failure and overheating	01.08.2015	41527	10.57	3376788	12	1
4050	Lightning strike of inverter	01.06.2025	6493	10.72	3411823	2	1
4051	Lightning strike of inverter	01.06.2025	36081	10.68	3382234	10	1
4060	Mismatch of module clamps	01.07.2010	4358	10.70	3413958	1	1
4061	Mismatch of module clamps	01.07.2010	24656	10.59	3393659	7	1
4070	UV aging of string cables	01.07.2025	5245	10.72	3413070	2	1
4071	UV aging of string cables	01.07.2025	60884	10.65	3357432	18	1
4080	Wrong/Absent cables connection	01.07.2010	2145	10.71	3416170	1	1
4081	Wrong/Absent cables connection	01.07.2010	77222	10.30	3341093	22	1
4090	Cabling damaged by rodents	01.05.2013	16264	10.65	3402052	5	1
4091	Cabling damaged by rodents	01.05.2013	43780	10.54	3374535	13	1
4100	Glass breakage of module, frameless	01.01.2011	40225	10.50	3378091	12	1
4101	Glass breakage of module, frameless	01.01.2011	330461	8.99	3087854	96	2

Distribution of total failure costs

Risk	Failure detection costs C_{det} (EUR)	Component replacement/ substituion costs $C_{rep/sub}$ (EUR)	Tansport and site preparation costs C_{trans} (EUR)	Labor costs to fix failure C_{lab} (EUR)	Total fixing costs C_{fix} (EUR)	Total down time costs C_{down} (EUR)	Total failure costs C_{fail} (EUR)
4000	1460	27702	5000	5571	39733	917	40650
4001	2790	166210	8720	34666	212386	201554	413940
4010	1460	27702	5000	5571	39733	258	39990
4011	2790	166210	8720	34666	212386	100638	313025
4020					0		
4021					0		
4030	500	3243	700	840	5283	75	5358
4031	2790	32430	5000	6900	47120	4681	51801
4040	500	3600	1000	429	5529	207	5735
4041	2790	21600	3560	1433	29383	12145	41527
4050	500	3600	1000	429	5529	964	6493
4051	2790	21600	3560	1433	29383	6699	36081
4060	500	2050	100	1708	4358	0	4358
4061	2790	12300	300	9265	24656	0	24656
4070	500	946	300	2620	4366	879	5245
4071	2790	5678	600	14600	23668	37215	60884
4080	500	108	100	790	1498	647	2145
4081	1790	648	100	3760	6298	70924	77222
4090	500	6360	2920	5811	15591	672	16264
4091	2790	12721	4700	11742	31953	11827	43780
4100	1460	27702	5000	5571	39733	492	40225
4101	2790	166210	8720	34666	212386	118075	330461

APPENDIX D – Risk Scenario Results

Business model 1 - risk scenario results

No	Risk	Name of risk	Start date of failure	Total fixing costs of risk C_{fix}	Total down time costs of risk C_{down}	Total failure costs of risk C_{fail}	IRR (incl failure)	Cumulative cash flow (incl failure)	Relative revenue Loss C_{fail}/R_{12}	Failure category
1	1061	Mismatch of module clamps	01.01.2011	670	0	670	12.52%	14.072	42%	1
2	1111	Soiling of modules	01.03.2021	936	926	1.862	12.59%	12.880	117%	3
3	1041	Fan failure and overheating	01.08.2018	1.680	1.605	3.285	11.09%	11.457	206%	4
4	1100	Module breakage by hail	01.08.2026	705	259	964	18.40%	125	60%	2
Total - non discounted static values				3.991	2.962	6.953	8.22%	7.789	435%	4

Business model 2 - risk scenario results

No	Risk	Name of risk	Start date of failure	Total fixing costs of risk C_{fix}	Total down time costs of risk C_{down}	Total failure costs of risk C_{fail}	IRR (incl failure)	Cumulative cash flow (incl failure)	Relative revenue Loss C_{fail}/R_{12}	Failure category
1	2000	Potential ind. degradation	01.01.2015	825	8	833	-0,47%	-596	74%	2
2	2031	Theft / vandalism of modules	01.02.2017	5.865	26	5.891	-3.78%	-5.670	523%	4
3	2071	UV aging of string cables	01.07.2030	484	375	859	-0.81%	-893	76%	2
4	2111	Failure of battery inververter	01.07.2023	1.545	937	2.482	-1.77%	-2.240	220%	4
Total - non discounted static values				8.719	1.805	10.524	-7.65%	-10.282	935%	4

Business model 3 - risk scenario results

No	Risk	Name of risk	Start date of failure	Total fixing costs of risk C_{fix}	Total down time costs of risk C_{down}	Total failure costs of risk C_{fail}	IRR (incl failure)	Cumulative cash flow (incl failure)	Relative revenue Loss C_{fail}/R_{12}	Failure category
1	3020	Hotspot of modules	01.01.2012	301.397	7.137	308.534	5.12%	5.271.398	27%	1
2	3101	Flooding of inverter	01.08.2017	200.856	108.369	309.225	5.21%	5.270.708	9%	1
3	3051	Lightning strike of inverter	01.06.2020	200.216	117.671	317.887	5.24%	5.262.045	28%	1
4	3011	Failure bypass diode/junct.	01.10.2026	1.800.535	332.118	2.132.653	4.06%	3.447.280	186%	3
Total - non discounted static values				2.503.004	565.295	3.068.299	2.92%	2.511.633	268%	4

No	Risk	Name of risk	Start date of failure	Total fixing costs of risk C_{fix}	Total down costs of risk C_{down}	Total failure costs of risk C_{fail}	IRR (incl failure)	Cumulative cash flow (incl failure)	Relative revenue Lo C_{fail}/R_{12}	Failure cate
1	4001	LP/TCO corrosion of CdTe mod.	01.07.2010	212.386	201.554	413.940	8.57%	3.036.017	120%	3
2	4101	Glass breakage of module	01.01.2011	212.386	118.075	330.461	9.01%	3.119.496	96%	2
3	4031	Theft/ vandalism of modules	01.02.2015	47.120	4.611	51.731	10.55%	3.398.227	15%	1
4	4081	Wrong/absent cables connec.	01.07.2025	6.299	65.787	72.085	10.%	3.377.872	21%	1
Total - non discounted static values				478.191	422.763	900.954	6.78%	2.549.004	260%	4

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