Investment risks of utility-scale PV: Opportunities and limitations of risk mitigation strategies to reduce uncertainties of energy yield predictions

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***Abstract* — Investment risks of utility-scale PV systems may arise from a wide range of sources: political stability in a region, interest rate levels and currency exchange rates or future energy price. However, the presence of stable political and economic conditions and feed-in tariffs or power purchase agreements may limit interest and price risks to acceptable levels. The technical risk of deviations between expected and actual life-time energy yield of a PV power plant is mostly influenced by the quality of energy yield predictions in case that system components correspond to their datasheet and guaranteed values and the maintenance concept is applied as expected. Recent publications estimate the standard uncertainty of life-time energy yield predictions to about 8%, which directly contributes to overall investment risk.**

In this paper we analyze two different strategies to reduce the influence of uncertainties of energy yield predictions on investment risks. The first strategy is diversification of risk, i.e. investing in a portfolio of systems. The second strategy is related to adjusted investment periods. It is concluded, that both strategies as well as the combination of these strategies are able to significantly reduce uncertainties. The resulting uncertainty of the lifetime energy yield for the combination of both approaches is estimated to about 3%.

***Index Terms* — utility-scale PV, investment risk, yield prediction.**

I. Introduction

Very large investments into utility-scale PV systems are usually driven by financial rules. Before any investment is undertaken, these rules dictate that risks are either ruled out or that an interest rate penalty is imposed, if the risk is deemed acceptable at an increased interest rate. Many risks are in fact not attributed to PV technology at all, for example political stability in a region, current and anticipated interest rate levels, currency exchange rates or the predicted future value of electricity in the region in question.

From a technical perspective, the origin of financial risk is easy to summarize: the most important factor is a potential lack of energy yield. The high relevance of PV energy yield predictions is therefore widely accepted.

Yield predictions are amongst the aspects deemed obligatory by the financing sector dealing with utility-scale PV projects, despite the fact that it is unclear, what risk penalty is added precisely. In energy yield prediction reports, the solar resource at the given location, the performance and the energy production over the expected life time of the PV power plant are detailed, using state-of-the-art knowledge in PV energy yield and solar resource modelling.

Many studies in very diverse research areas have already contributed to more accurate yield assessments. However until now only a few publications are dealing with uncertainties of the predicted lifetime energy yield of PV systems, e.g. [1–3].

In this paper, we detail the uncertainties of state of the art lifetime energy yield predictions for PV systems and analyze the potential of different investment strategies to mitigate investment risk.

II. Methodology and General Approach

Based on an assessment of uncertainties for yield predictions of individual PV power plants, we identify and assess two different strategies to reduce uncertainties and mitigate risks for an investment.

The first strategy is straightforward and well-known: risk diversification, i.e., investing in a portfolio of PV power plants rather than a single system as to distribute and thereby lower overall risk.

In the second strategy, we consider investments are made for PV power plants that are already in operation. Here, the investment period is limited to a selected duration. The idea of how risk might get mitigated this way is illustrated in Fig. 1. As shown, some of the uncertainties involved in energy yield predictions arise due to a lack of detailed knowledge of site conditions and system behavior, before the system is operating. These uncertainties can be reduced after some years of operation by using on-site meteorological measurements and system monitoring data. After first operational experience and preparation of a site and PV system adapted yield prediction the PV power plant is sold to an investor (or transferred to a yieldco). Other causes of uncertainty, however, are related to long-term effects and therefore become relevant only towards longer operational durations of the PV power plant. Consequently, we presume that there exists a period in between, which offers lower investment risks. As an example we will analyze an investment period lasting from the 4th to the 15th year of operation. After this period the system could be resold to less risk-averse investors. Uncertainties of the future value of the PV system and the reselling price (as well as correlations between the end of the investment period and this price) exist and have to be taken into account. However, they are outside the scope of the present paper.

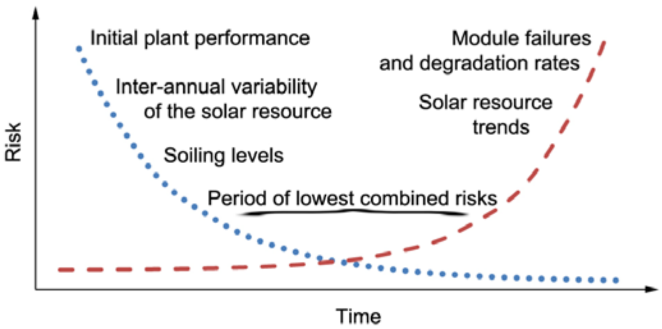

Fig. 1. Technical risks over the lifetime of a PV plant.

III. Detailing Uncertainties of Yield Predictions

In a recent study on uncertainties in PV energy yield predictions, we summarized our current estimates on the combined uncertainty of predicted yield over the entire lifetime of a PV power plant [2]. As there are long-term factors that influence expected yields as well as uncertainties, this estimation separates initial and long-term effects and includes an estimation of the development of the uncertainties over the lifetime of the PV system. Typical results of such an assessment for a system equipped with crystalline silicon modules and a moderate (middle European) climate are shown in Fig. 2. Note that all uncertainties within this paper are given as standard uncertainties.

The initial uncertainty of 5.6% for the first year of plant operation shown in Fig. 2 results from the combination of uncertainties of the initial solar resource assessment (4.2%) and uncertainties arising from initial performance ratio (PR) modelling (3.6%). Uncertainties for the solar resource consist of a 3% uncertainty from the assessment of global horizontal irradiance (GHI) at the location under consideration and another 3% for transposition to irradiance in plane of array (GPOA). For initial PR modelling the uncertainties consist of uncertainties of the system modelling itself with 3% and an estimated uncertainty of 2% for potential differences between nominal and actually installed STC power [See 2, Table III for more details].

Long-term solar resource trends [4, 5] as well as long-term degradation [6] and possible reversible PR changes (e.g. due to soiling) affect energy yields and uncertainties of the prediction over the plant lifetime.

There are a few publications, that analyze possible future changes in the solar resource based on projections from global climate models [7, 8]. However such projections based on the current generation of climate models are still subject to considerable uncertainties. For this reason, up to now projections of long-term changes in irradiance are not considered in the calculation of expected yields, but are included as uncertainties. The magnitude is estimated to a possible change rate of 3%/decade [9]. Long-term changes in PR are estimated as a linear change rate of -0.5%/year, the uncertainty is assumed to be 0.5%/year.

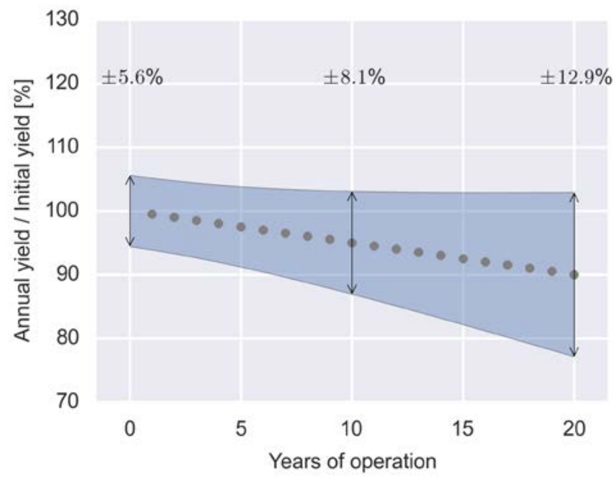

Fig. 2. Expected lifetime energy yield and uncertainties for a PV plant. The dotted line shows the mean expected development of the yield compared to initial yield (interannual variations not included); uncertainties are shown as blue plane.

Initial and long-term uncertainties (increasing with time) are combined for all single years of the expected lifetime of the system (20 years in Fig. 2). The resulting combined uncertainty for the expected energy yield integrated over the lifetime of the system is about 8.5%. Initial, long-term and combined uncertainties will vary depending on environmental conditions and details of the PV power plant under consideration. Especially they maybe higher for regions closer to the equator, were a growing number of PV power plants are built today.

It is important to note, that Fig. 2 shows expected energy yields in typical years. Interannual variations in energy yields due to the variability of the solar resource are not included in the uncertainty estimation. The aim of the assessment is to derive an estimate on the overall yield over the lifetime of the PV system. The magnitude of these variations is site specific (e.g. lower at locations with general high irradiance conditions as in arid climates). For 26 PV systems analyzed in [2] the standard deviation of annual yields from their trend-corrected mean is about 5% in average (see Fig. 3 for a visualization of all measured deviations for these systems). This means that actual annual yields may deviate from the expected yield in a typical year by about ±10% for the first years of operation and by more than ±15% in the last years of operation.

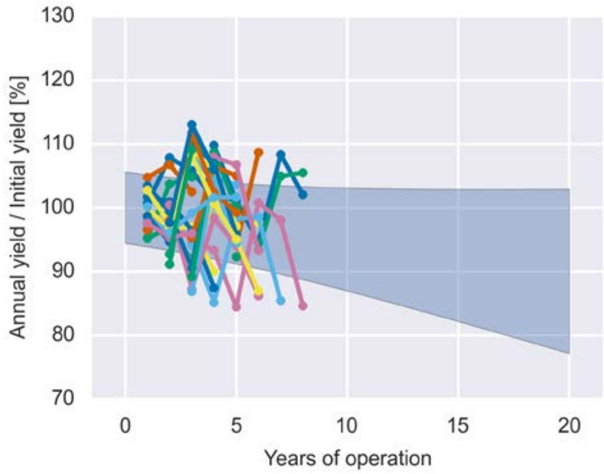

Fig. 3. Annual deviations of measured energy yield from expected initial yield for 26 systems located in Germany and Spain. Note, that the years of installation are different for these systems. As a result, true correlations between energy yields in individual years maybe underestimated for this example.

IV. Assessment of Risk Mitigation Strategies

Based on the uncertainty assessment for a single PV power plant over the entire technical lifetime in the previous section, we will now assess the potential to reduce uncertainties with the two aforementioned strategies and a combination of both strategies.

A. Diversification by Investment in a Portfolio of PV Systems

Often investments risks are spread by a pooling of different investment objects. This is also the case for the PV industry as the recent trend to yieldco's show. The investment in a portfolio of systems may also be an option for risk-averse investors, such as pension funds or assurance companies. In the following we will assess the implications of such an investment strategy on the uncertainty estimation from section III. Note that it is assumed that the portfolio consists of a reasonable large number of systems. The assessment (as well as the assessment in the following sections) can only provide typical estimations. The estimated uncertainty may vary depending e.g. on the number, the location and the distribution of the systems, the module technology used and the system configuration. It is possible to estimate the uncertainty of the energy yield of the PV system portfolio by using statistical methods and existing yield predictions and uncertainty estimations for all single systems. Here, we will instead discuss the influence on the standard uncertainty for every source of uncertainty and derive the combined uncertainty for the whole portfolio from these estimations.

The advantage for an energy yield assessment of multiple systems is that random errors may cancel out. Based on literature, it can be assumed that this applies to the assessment of GHI [10, 11] as well as on the transposition to GPOA. With the estimation of a 2% uncertainty for both factors the combined uncertainty of the initial solar resource assessment is reduced to 2.8% (compared to 4.2% for the estimation in section III for a single location, the numbers from the base case in section III will be given in brackets for all changed assumptions in the following). It can be assumed that a reduction will also occur for initial PR modelling, both for the modelling itself [12] as well as for deviations between actual and nominal STC power. We estimate the uncertainty to 1.5% (3%) for system modelling and to about 1% (2%) for power deviations.

The use of different module types and system configuration may also slightly reduce the uncertainty of PR changes. With distributed locations, also a slight reduction of the uncertainties resulting from possible future changes in the solar resource may occur. We estimate these uncertainties to 0.35%/year (0.5%/year in section III) for the PR changes and to 2.5%/decade (3%/decade) for solar resource trends.

The results of the uncertainty assessment of the energy yield for a portfolio of PV systems are shown in Fig. 4. The combined uncertainty for the expected energy yield of the system portfolio integrated over the lifetime is about 5.8%, which is a reduction by about one third compared to the uncertainty of the yield for a single system. The expected reduction of uncertainty is in line with the observed reduction of the mean deviations compared to the deviations of single systems in [2].

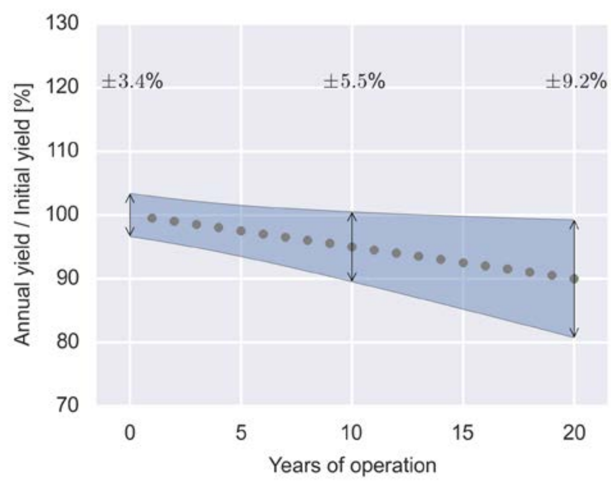

Fig. 4. Expected uncertainties for a portfolio of PV systems

An additional advantage of the pooling of systems is the drastic reduction of the interannual variability due to smoothing effects. As an example, the measured variability of the mean annual yield for the portfolio of 26 systems from Fig. 3 is shown in Fig. 5. This smoothing will result in a more continuous cash flow not only on annual but also on seasonal basis especially for a portfolio with systems located at both sides of the equator. The magnitude of this smoothing effect is dependent on the number, the location and the spatial distribution of the systems.

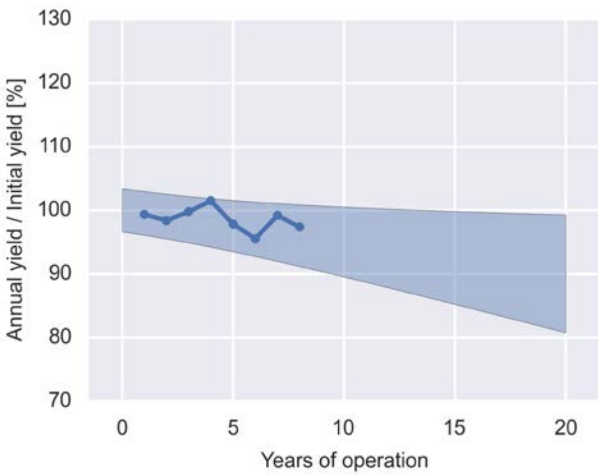

Fig. 5. Annual deviations of measured energy yield from expected initial yield for a portfolio of 26 systems located in Germany and Spain. See Fig. 3 for the variability of the individual systems. As for Fig. 3 true deviations in individual years maybe higher, than in the example.

B. Adjusted Yield Predictions and Investment Periods

For the second strategy we assume, that three years of high quality monitoring data is available for the system under consideration. These local measurements can be used to adjust the time series of irradiance and temperature, which used for the prediction of energy yields. As we assume that only three years of measurement data are available, the measured data itself cannot be used to predict future yields due to the high influence of interannual variations.

For this reason, usually satellite derived irradiance time series with a minimum time span of 10 years are used to predict the (remaining) lifetime yields. There are different approaches to adapt and to combine these data with ground measurements [e.g. 13, 14] with reasonable high accuracy. The adapted time series in the monitoring phase can then be used to train the modelling chain to derive adapted parameters for PR modelling.

The focus within this procedure is to match the measured final (annual) energy yield of the system with an appropriate set of PR modelling parameters in combination with an adapted time series rather than to match the results of all modelling steps e.g. GHI, GPOA and PR. Measurement uncertainties of irradiance and PR are considerably higher compared to uncertainties of energy meters one the one hand and on the other hand this allows to perform the adaption in cases were no high quality meteorological measurements (or no such measurements at all) are available. The match of measurement with simulation should be checked for annual and monthly energy yields to ensure that the variability of the energy yield is covered by the modelling. If modelled monthly yields in the training phase match considerably well, it is likely, that the derived set of parameters is able to predict annual system outputs for the whole time series. We estimate that a detailed analysis of the system and measurement data will allow a considerable reduction of the initial uncertainties for annual energy yields to about 2%. Systems at locations with higher soiling losses will have higher initial uncertainties compared to the estimation of 5.6% in section III. It should be possible to hold the estimated reduced uncertainty of about 2% also in these cases if adapted cleaning procedures are applied.

Long-term uncertainties may not be reduced by the availability of three years of measurements. For this reason, our basic assumptions for long-term uncertainties remain unchanged (3%/decade for solar resource trends and 0.5%/year for PR changes, see section III). However the reduction of the investment period will reduce their influence on the uncertainty of the lifetime energy yield. Shorter investment periods than the 12 exemplary years chosen here will further reduce the influence of long-term uncertainties.

The result of the uncertainty assessment for the energy yield of a single PV system with adapted yield prediction and investment period is shown in Fig. 6. The combined uncertainty for the expected energy yield integrated over the lifetime of the system is about 4.2%, which is a reduction by about one half compared to the estimated uncertainty from section III.

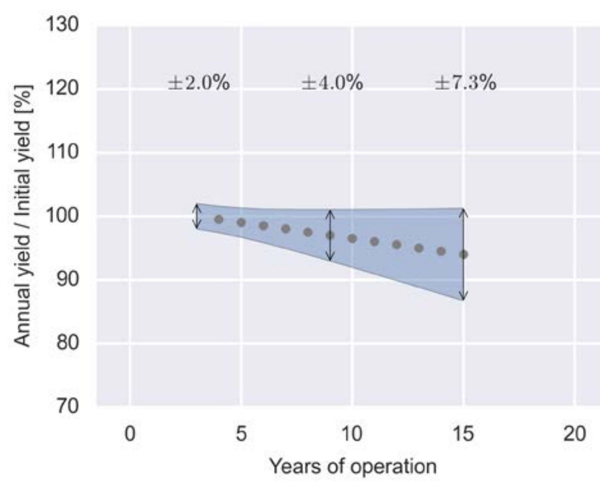

Fig. 6. Expected uncertainties for an adjusted yield prediction and a reduced investment period

C. Combination of Both Approaches

If adapted yield predictions and investment periods are applied to a portfolio of system, uncertainties can be further reduced.

For initial PR modelling the uncertainty for the modelled energy yield of the portfolio is estimated to 1%. Long-term uncertainties are estimated to be unchanged compared to section IV A (0.35%/year for PR changes and 2.5%/decade for solar resource trends). Due to the reduced investment period, however, their influence on the uncertainty of the lifetime energy yield is reduced also.

The results of the uncertainty assessment for the combination of both approaches are shown in Fig. 7. The combined uncertainty for the expected lifetime energy yield of the system portfolio with adapted yield predictions and the selected investment period is about 2.9%. This is a reduction by about two thirds compared to the estimated uncertainty of the yield for a single system from section III.

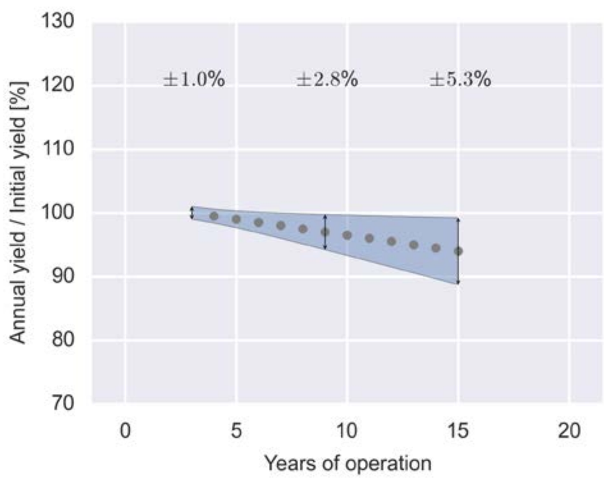

Fig. 7. Expected uncertainties for a combination of both strategies

V. Conclusion

We evaluated the potential of two investment strategies to reduce the uncertainty of the predicted lifetime energy yield. Both strategies as well as the combination of these strategies help to significantly reduce uncertainties of lifetime energy yield predictions. For the combination of both approaches our estimate amounts to about 3% uncertainty compared to an uncertainty of about 8% for investments in a single PV system for the whole lifetime.

~~Beside~~ Aside from the reduction of the uncertainty also a smoothing of the interannual variability and therefore the cash flow from the investment can be achieved. In combination with the possibility of insurances, hedging or guarantees for expected lifetime yields, investments in PV power plants offer investment possibilities with very low risks.

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