Uncertainties in Yield Assessments and PV LCOE

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Executive Summary

Yield assessments (YA) and Long-Term Yield Predictions (LTYP) are a prerequisite for business decisions on long term investments into photovoltaic (PV) power plants. Together with cost data (CAPEX, OPEX and discount rate), the output of a YA and LTYP (utilisation rate, performance loss rate and lifetime) provides to the financial investors the parameters needed for the calculation of the Levelised Cost of Electricity (LCOE) and to assess the cash flow model of an investment with relative Internal Rate of Return (IRR) and Net Present Value (NPV).

YA and LTYP outputs should be provided with a related exceedance probability. This gives the right tool to stakeholders involved in PV projects to take the best decision in terms of risk-aversion. A reduction in the uncertainty of the energy yield can lead to higher values for a given exceedance probability and hence a stronger business case. Various efforts in the literature show the importance of having a common framework that can assess the impact of technical risks on the economic performance of a PV project.

The most important parameter influencing the energy yield assessment is the site-specific insolation. Several aspects need to be considered: reliability of the database, interannual variability, long term trends.

Site adaptation techniques combine short-term measured data and long-term satellite estimates. Short periods of measured data but with site-specific seasonal and diurnal characteristics are combined with satellite-derived data having a long period of record with not necessarily site-specific characteristics. Upon completion of the measurement campaign, which is typically around one-year, different methodologies can be applied between the measured data at the target site, spanning a relatively short period, and the satellite data, spanning a much longer period. The complete record of satellite data is then used in this relationship to predict the long-term solar resource at the target site. Assuming a strong correlation, the strengths of both data sets are captured and the uncertainty in the long-term estimate can be reduced.

In Müller et al [1] an analysis on long-term trends for measured in-plane irradiance, Performance Ratio and energy yield for 44 rooftop installations in Germany was performed showing an average increase of in-plane irradiance of 1.1 %/year or about 11 %/decade over the period 2008 to 2018 for these systems. The increase in irradiance was especially higher than the observed Performance Loss Rate so that the energy yields of the systems analysed increased over the years with an average trend of 0.3 %/year.

[1] B. Müller and K. Kiefer, "Long-term trends of in-plane-irradiance, energy yield and performance for PV systems," Nov. 07, 2019, doi: 10.13140/RG.2.2.16442.54721.

The typical output of Yield Assessments should report the contribution to each derating factor, starting from the Global Horizontal Irradiation to the energy injected in the grid. The starting point of PR = 100 is considered after applying the horizon shading as this become the annual insolation seen by the PV modules. The following table shows a best practice in providing an overview of gains/losses along each modelling step and the related uncertainty. The uncertainty related to each modelling step can be provided already referred to the irradiation/yield value or to the parameter that is modelled. The value in the table for the specific yield (including its uncertainty) is to be understood as an average value over the entire operating period. The possible deviations between the yields for individual recorded years and the specific yield calculated can be assessed by including interannual variability.

Annual values	**uncertainty**	**value**	**gains/loss**	**PR**
	%	kWh/m^2	%	%
global irradiation on horizontal plane	4.0	1248		
irradiation on module plane	2.5	1448	16.0	
shading				
horizon shading	0.5	1445	-0.2	100.0
row shading	2.0	1422	-1.7	98.3
object shading	3.0	1422	0.0	98.3
soiling	0.5	1414	-0.5	97.9
deviations from STC				
reflection losses	0.5	1376	-2.7	95.2
	%	kWh/kWp	%	%
spectral losses	0.5	1363	-1.0	94.3
irradiation-dependent losses	0.8	1342	-1.5	92.9
temperature-dependent losses	1.0	1309	-2.5	90.5
mismatch losses	0.5	1298	-0.8	89.8
DC cable losses	0.5	1287	-0.8	89.1
inverter losses	1.5	1272	-1.2	88.0
inverter power limitation	0.5	1272	-0.1	88.0
additional consumption	0.5	1270	-0.1	87.9
AC cable losses low voltage	0.5	1265	-0.4	87.5
Transformer medium voltage	0.5	1253	-0.9	86.7
AC cable losses medium voltage	0.5	1252	-0.1	86.6
Transformer high voltage	0.0	1252	0.0	86.6
total	**6.5**	**1252**		**86.6**

For example, for temperature-dependent losses, the value of uncertainty could be referred to the temperature variability of the profile used in the assessment or to the temperature model used in the assessment. The ambient temperature variability and the various temperature models will lead to a different contribution in terms of yield loss and in terms of uncertainty.

An emerging challenge in YAs is also due to the deployment of novel technologies (e.g. bifacial PV modules) with a contribution in terms of uncertainty that needs to be properly assessed.

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Building upon the knowledge available in the literature and the previous IEA PVPS Task 13 report [2], in this report we have moved forward from the uncertainty framework in yield assessment to two real implementations of it and the impact that uncertainties can have on lifetime yield predictions, on the LCOE and on the cash-flow.

One of the most relevant question that we have tried to answer is also the following:

How reliable are YA's?

This is an apparently simple question; however, the answer is not equally simple. Typically, investors require one YA. In some cases, more YAs might be requested if results are unclear. The various YAs can be averaged to assign a purchase value to a given project. In any case the question remains unanswered: why different assessors obtain different answers? Is one YA more reliable than others?

Investors know that past performance is no guarantee for future results. This maxim also applies to long-term yield assessments and the LCOE that can be determined from these, also within the context of a changing climate. Yield Assessment is an essential step in a PV project, as it helps to determine whether a system will be funded or not. However, the YA is not only about the software used, it is mainly about the user. YAs may not be as reliable as expected, and in this report, we demonstrate how seven highly skilled specialists did not arrive at the same result, having been provided the same detailed inputs.

Independent yield assessors were in fact asked to provide YAs and LTYPs for two sites, namely, Bolzano in Italy and Alice Springs in Australia.

For the Bolzano site, the P50 ranged between 1095 and 1406 kWh/kWp, P90 ranged between 997 and 1274 kWh/kWp. The average value for the initial YAs is 1278 kWh/kWp with a STD (σ) of 9.7 %. Taking into account the estimated Performance Loss Rates of the LTYPs, the average annual energy yield over the time period the system is in operation (2010 to 2019) would be 1253 kWh/kWp. The measured average yield in the period is 1275 kWh/kWp.

For the Alice Springs site, the P50 ranged between 1757 and 1985 kWh/kWp and the P90 between 1631 and 1819 kWh/kWp. The average value for the initial YAs is 1878 kWh/kWp with a STD (σ) of 3.9 %. The system has been in operation since 2009 with an initial yield of 2075 kWh/kWp and 1926 kWh/kWp as 10-year average.

As seen from the YA exercises for Bolzano and Alice Springs, differences in these stem primarily from personal experience and assumptions by the modeler, of which

(i) the irradiance database selection and site adaptation (especially for mountainous terrain),
(ii) degradation/PLR assumption,
(iii) total modelling uncertainty values (as seen in the P50 and P90 ranges) and
(iv) soiling and far/near shading had the largest impact on the determined result.

The direct flow-on consequence from this is that LCOE values will also exhibit a variance, on top of the additional modelling assumptions that can be employed for LCOE calculations. Determining P50 and P90 values for LCOE results and highlighting the assumptions/modelling chain will be important. From an industry perspective, it would be beneficial if more "live" post-mortem analyses (i.e. comparison of the LTYP and measured data, at e.g. every 5 years of system life) would be made and published. These can then be used as crucial feedback and inputs for YA modelers, financiers, and insurers.

To conclude, we believe that together with the previous report [2], we have provided all the needed information to understand if one YA is more reliable than other and which input and output data must be provided by the assessor to reach this conclusion.

[2] C. Reise, "iea-pvps.org - Uncertainties in PV System Yield Predictions and Assessments," 2018. Accessed: Feb. 28, 2020. [Online]. Available: http://www.iea-pvps.org/index.php?id=477.

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