Whitepaper

Benefits of both pyranometer and satellite irradiance data for utility-scale solar energy parks

3E

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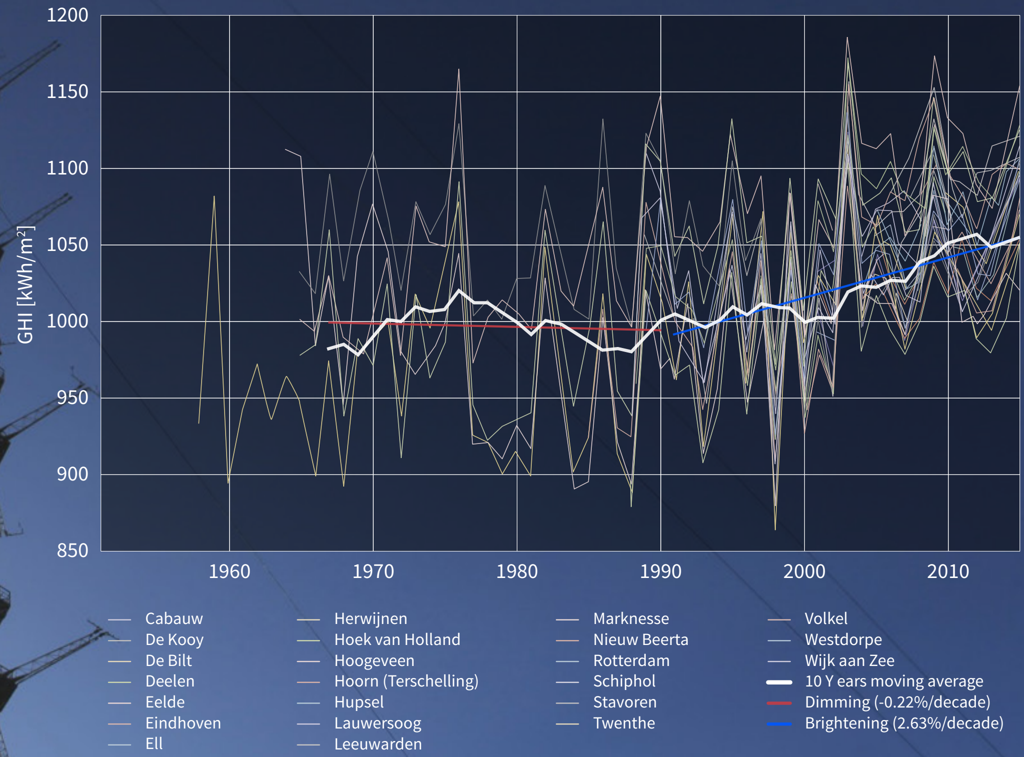
Benefits of both pyranometer and satellite irradiance data for utility-scale solar energy parks

In the present utility-scale solar power market, with high competition and falling component and maintenance prices, showing positive financial results (both in margin and asset value) can be challenging. By using state-of-the-art solar plant performance monitoring and assessment techniques, profitability can be maintained, or even increased.

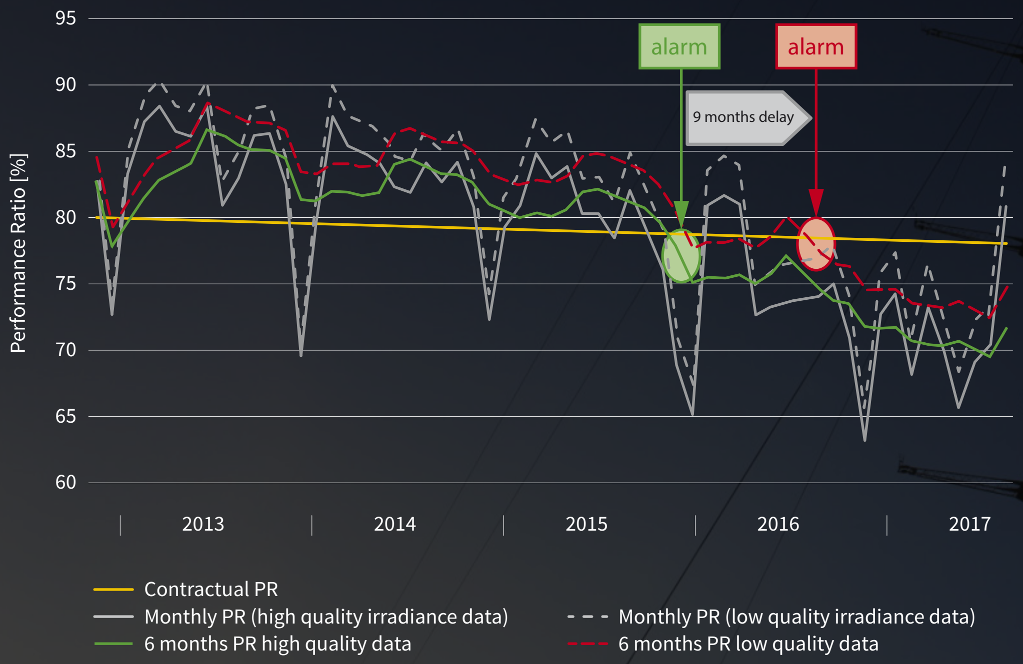
Adequate monitoring of a PV plant is crucial to evaluate its performance and improve the operation and maintenance of it. Irradiation data is the most important environmental factor determining the production of the solar array. Accurate irradiation measurement is essential for determining the overall performance of a solar park, since the energy provided at the earth's surface by light from the sun and sky has a large variability, both in space and in time.

As shown in the figure (irradiation data from 32 meteorological stations spread throughout the Netherlands), there is a considerable spatial and temporal variation, even over a relatively small and geographically uniform area such as the Netherlands. The figure particularly highlights the yearly variability compared to the yellow line that shows the 10-year moving average.



A few percent error in irradiation measurements, together with small and unnoticed plant under-performance, can easily result in lost annual revenues ranging from tens of thousands of Euro for a 5 MW installation up to a million Euro for a 250 MW plant. Undetected under-performance can easily cause the Performance Ratio to drop below a contracted value, resulting in financial penalties. Investment in good quality irradiance measurement equipment usually pays back within 1 to 2 years.

The importance of accurate irradiation data is shown in the figure below for a degrading 5MWp PV plant: the contractual performance ratio (PR) is plotted in orange (taking a small, predicted degradation into account). There is a badly maintained, low quality, degrading on-site sensor (dashed lines for monthly and 6 months PR) and high quality irradiance data (solid lines for both monthly and 6 months PR) available. The figure indicates that in this case the contractual performance ratio threshold would get triggered 9 months later due to bad irradiation sensing.

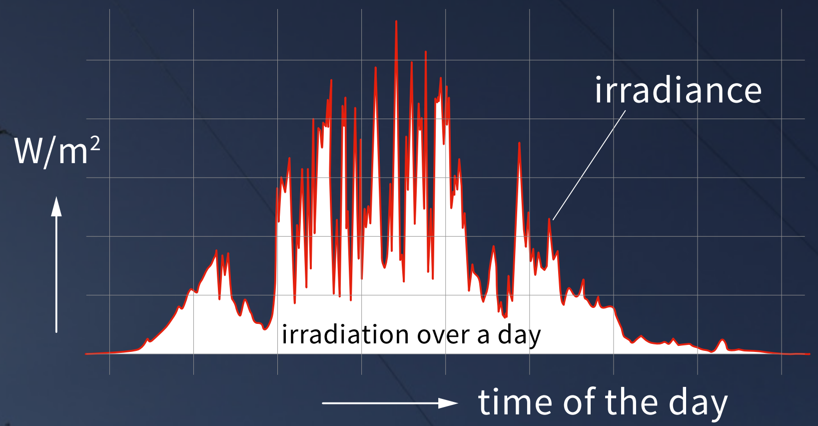


This whitepaper guides you through best practices in irradiance measurements for utility-scale solar energy plants, and the importance of irradiance measurements for EPCs, O&M parties, asset managers, owners and financial stakeholders.

Irradiance or irradiation?

Irradiance and irradiation are often used as synonyms but officially, they differ:

- Irradiance is the power of the sunlight at a specific moment (expressed in Watt per square meter (W/m^2)).
- Irradiation is the sunlight energy over a period of time, e.g. an hour, a day or a year. Irradiation is the sum of irradiances over time and is (often) expressed in kilowatt-hour per square meter (kWh/m^2).

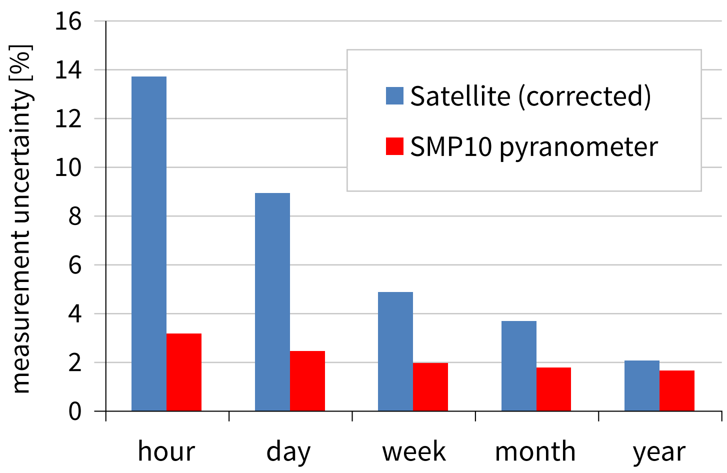


Best practices in irradiance measurement

In general, two independent sources of data for Global Horizontal Irradiance (GHI) are available:

1. On-site ground measured data
2. Data derived from satellite instrument measurements

The local irradiance is usually measured by a pyranometer and is very accurate (low uncertainty, if the equipment is well installed and maintained). When averaged and/or integrated over relatively short periods from as little as a minute to an hour, day, or week a pyranometer is the most accurate solution. But data derived from satellite measurements comes close to the on-site measurement uncertainty over longer time periods such as months and years.



In practice, both satellite and on-site data are often used in parallel and correlated in plant monitoring software (such as SynaptiQ Solar by 3E). However, the varying measurement uncertainties over different time-scales must be borne in mind.

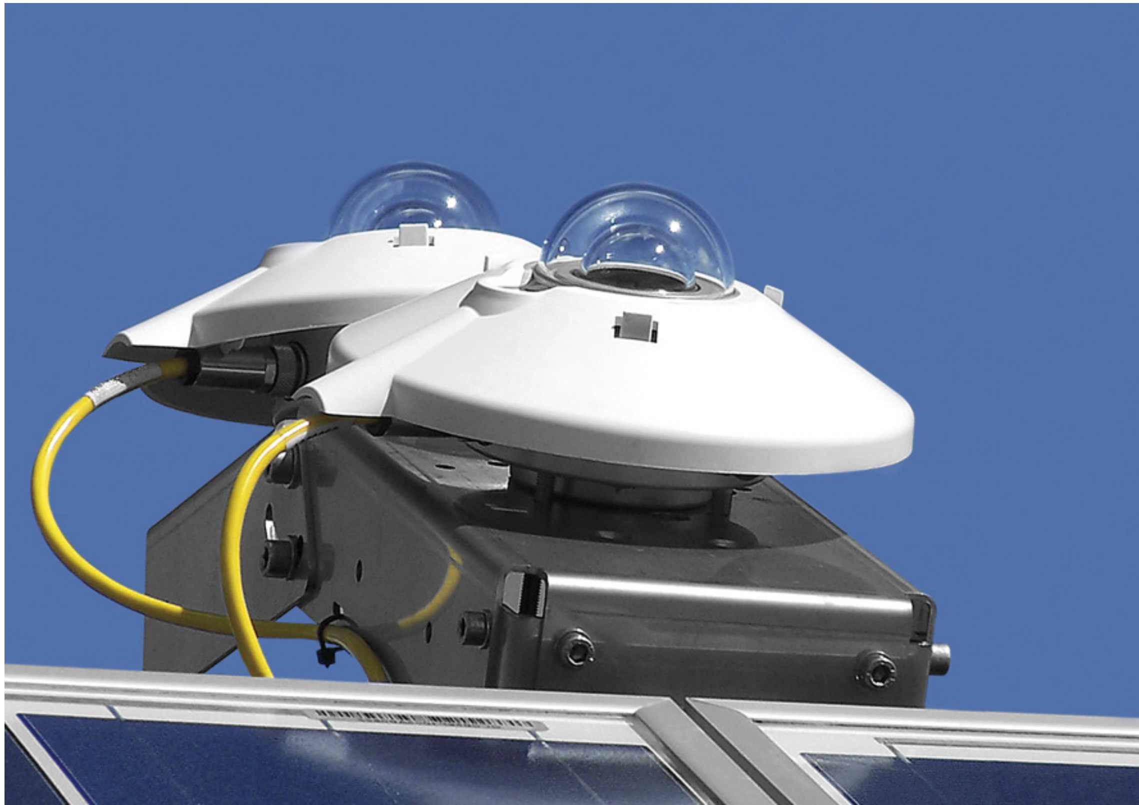
On-site collected data

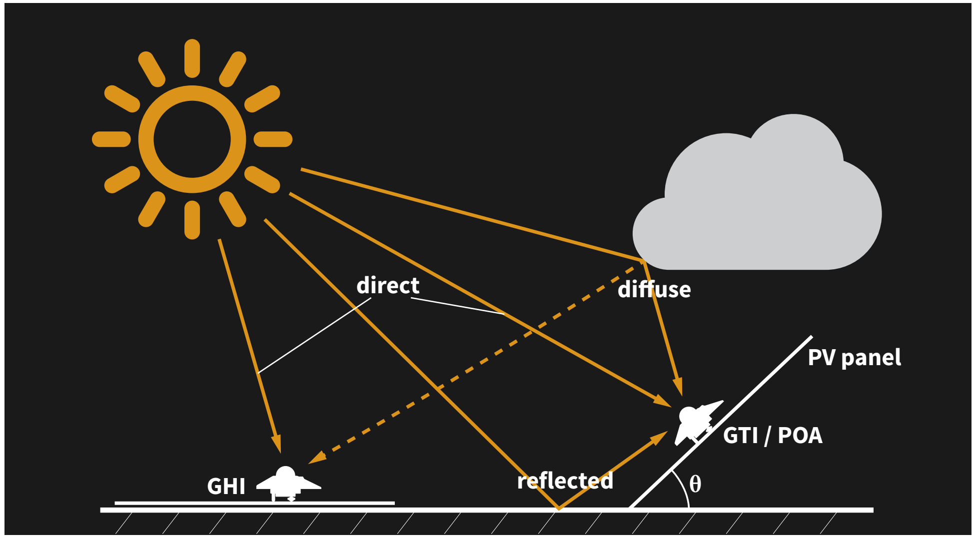
On-site irradiance data is collected by sensors placed at well-chosen locations in a solar park and they must be able to reliably measure irradiance differences of a few percent over long time periods, as shown in the annual irradiation chart for the Netherlands. By specification, secondary standard pyranometers (e.g. Kipp & Zonen CMP10 or SMP10) are most fitted for the job. Their modest price, compared to the multi-million Euro investments in a solar park, and their role in plant performance monitoring and fault and degradation analysis, implies that the business case for installing these instruments is very positive.

On-site data is needed for real-time and short-term performance monitoring, for analysis of solar plant issues (e.g. panel or system degradation), and for maintenance and repair decisions. It is also used to fine-tune the satellite data for the local conditions.

Two separate local solar irradiance measurements are necessary:
1. Irradiance in the horizontal plane, Global Horizontal Irradiance (GHI)
2. Irradiance at the same tilt and orientation as the solar panels, termed Plane of Array (POA) or Global Tilted Irradiance (GTI)

On-site POA measurements are most important, since this parameter is a major input for monitoring the expected yield and performance of the solar plant. Unlike GHI, POA takes into account reflections from plant structures and the ground that are in the view of the PV panels and the tilted pyranometer. For example, the reflection of white sand is much higher than that of black soil.





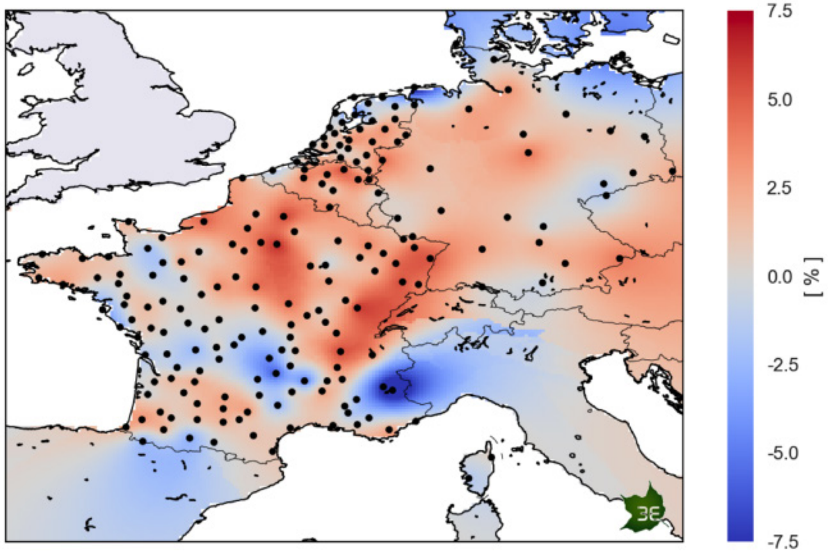
To collect high quality on-site irradiance data, the pyranometers must be installed precisely and maintained well; with regular dome cleaning, alignment check and recalibration. On larger plants, measurement at multiple points is necessary to increase measurement accuracy as clouds transit the site and there where panel arrays are installed at different angles (for example on a hillside).

Additional pyranometers are advisable for redundancy and for backup during recalibration. If one pyranometer mounting becomes distorted, for example by a mowing lorry or a cleaning robot, a second pyranometer nearby will indicate that something is wrong. This happens more often than you might think! Inter-comparison with additional pyranometers and/or satellite data will tell you where the problem is.

Satellite irradiance data

Satellite irradiance data is retrieved using models to derive cloud, precipitation, irradiation, and other parameters from measurements by optical instruments on board of satellites. State-of-the art satellite irradiance data providers like e.g. 3E's Solar Resource Data Service, use advanced cloud physical properties (CPP) models. The use of CPP models has increased significantly the accuracy of satellite irradiance data throughout the day and under complex cloudy conditions.

The yearly difference between satellite irradiation data from 3E and on-site measured data collected by the national weather services of Belgium, France, Germany, and the Netherlands over 200 meteo stations is shown in the figure.



Percentage difference between satellite irradiance data from 3E and ground station data in 2012 using high quality pyranometers maintained by the national public weather services

The percentage difference between 3E's satellite irradiation data and high accuracy on-site measured data over one year is in the order of ±2.5% for many places across Western Europe. The figure also highlights the importance of having dense networks of high quality on-site measurements as this enables the continuous accuracy improvement of satellite irradiance data over complex conditions. Moreover, satellite irradiance models need also to adjust to different satellite technologies to cover the entire globe and therefore dense networks of trustworthy public weather stations are needed to further improve the accuracy of the models across the world.

Satellite irradiance data is increasingly being used in both, utility-scale solar parks and in smaller installations since it is easy to acquire, just a subscription to a service provides high availability of data with good time resolution and spatial coverage. Furthermore, for most locations on earth, in addition to near real-time data, satellite data is available going back at least 10 years providing a useful historical database for site prospecting and for optimising the site-specific design of solar power plants. Therefore, this source of irradiance data is often used as an input for long-term yield assessment and to calculate a reference yield for monitoring and business reporting.

Best practice:
combining pyranometer and satellite irradiance data

Robust statistical analysis in solar energy plant monitoring software (like SynaptiQ) combines both on-site pyranometer and satellite-derived sources into validated and precise irradiance data for a specific plant.

These two data sources are highly complementary and should be used together to obtain redundancy and cross-checks for accurate data over appropriate time-scales.

Reasons to combine data sources:

- Satellites and pyranometers are fully independent sources of irradiance data that can be compared, analysed and correlated to determine reliable site data.

- For monthly to annual reporting of the overall plant performance by O&M contractors and asset managers, satellite data are a valid and reliable source that can be validated by comparison with on-site pyranometer data.

- A CPP is a physics-based, empirically adjusted, algorithm that enables the continuous monitoring of the physical properties of clouds and the quantification of their influence on surface solar irradiance. However, the GHI data still needs to be aggregated over relatively long periods to achieve a low uncertainty. The Plane Of Array (POA) irradiation can be calculated by another step in the algorithm; however, contributing ground reflections between solar panel arrays (e.g. snow) cannot be detected by satellites.

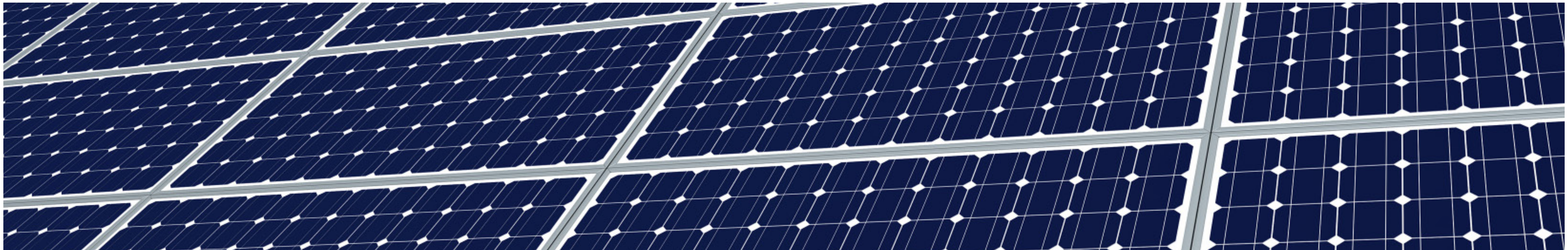
- For long-term yield estimates as computed by investors, installers and consultants, satellite-derived data are a viable source. In case of doubt, this should be evaluated with one or two years of data from a well-maintained solar monitoring station in the neighbourhood and the satellite algorithm fine-tuned as necessary.

- Fault detection and analysis by an O&M contractor requires hourly and daily on-site irradiance data. High quality and well maintained pyranometers (such as Kipp & Zonen's CMP10 or SMP10) are the first choice; satellite data may be used as back-up if the instruments fail or appear to be badly maintained.

- Gradual degradation of the solar plant (panels, connections and inverters) can only be detected by very high quality irradiance data collected by on-site instruments.

- Satellite data may also serve to validate the proper calibration and configuration of pyranometers in case of doubt. For large deviations, cleaning needs or shadowed sensors, satellite data analysis may spare the O&M operator a site visit.

The best practice is to use both on-site pyranometers and satellite data services to obtain accurate irradiance data for solar plant performance monitoring over both short and long time-scales.



Example of the value of irradiance data to solar plant stakeholders

As an example, let us consider a typical 5 MW solar power plant in Europe.

It produces 1200 kWh/kWp
The electricity is sold at 120 EUR/MWh
Expected annual revenues are 700k Euro
Contracted annual O&M costs are 50k Euro

EPC company

When developing, designing and building a utility-scale solar energy power plant the most cost-effective irradiation measurement solution will normally be chosen that is compliant with the specifications brought forward. However, during the various stages of acceptance testing, irradiation measurements become critical to justifying the plant performance.

A clear irradiation monitoring approach, with a well designed and implemented measurement chain, is therefore key to avoiding lengthy performance and availability discussions that delay payments. Expensive on-site corrective interventions due to mounting, cabling, calibration, communication or placement issues can be avoided.

Example case:

Typical outstanding payment at the Provisional Acceptance Certificate (PAC) stage on a 5 MWp project is in the order of 200k Euro. Delayed payment hinders the cash position and therefore investments in new project developments. At the Intermediate Acceptance Certificate (IAC) and Final Acceptance Certificate (FAC) stages, poor irradiation policies can result in significant liquidated damages for the EPC. Typically, for a 5 MWp plant, if 2 % under-performance is suspected, the penalties at stake could also be of the order of 200k Euro.

O&M contractor

As an O&M contractor on a large portfolio of solar assets, it is important to have adequate, cost-effective, reliable and indisputable irradiation monitoring. High quality on-site measurements of performance parameters with remote analysis (including irradiance) lead to efficient problem solving (with or without a site visit) and contribute to the margin on the contracted O&M fee.

Example case:

Typical O&M fee on a 5 MWp project is in the order of 50k Euro per year, while annual revenues amount to 700k Euro. The cost of going on-site differs per location (determined by travel costs and wages) but 1 day on-site for in-depth local investigation and fault analysis typically costs 0.5 to 1k Euro.

Asset manager / owner

Managing solar assets is about contracts and performance, including guarantees and indemnities for underperformance. Without reliable data, particularly for irradiance, Performance Ratio calculations are meaningless, degradation becomes undetectable and availability cannot be calculated. Data integrity, maintenance and the re-calibration of on-site pyranometers (and other measurement equipment) should be part of the contract with the O&M contractor.

Example case:

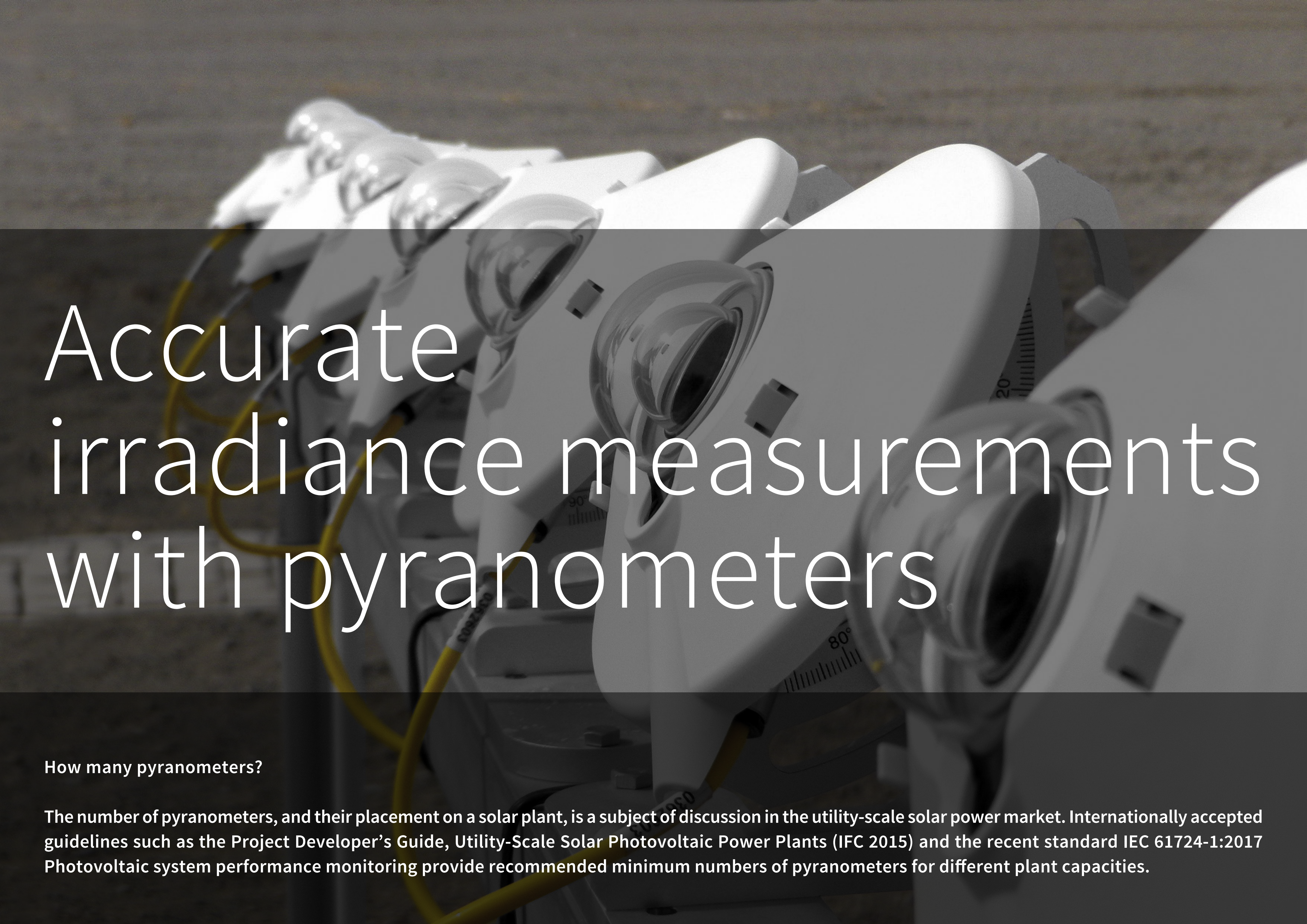
An undetected performance degradation of 2% over 5 years can result in a revenue loss of 70k Euro.

Debt finance / investor

Short-term performance issues of the assets are not very relevant. However, in order to assess Debt Coverage Ratio (DCR) versus the business plan, medium-term to long-term plant performance issues should be distinguished from irradiation differences. A reliable source of site-specific irradiation data is key to being forewarned of up-coming debt finance issues.

Example case:

Working with high probability (P90) scenarios for solar assets requires high quality, validated irradiance data as an input and the asset manager should be able to report degradation figures. As previously mentioned, an undetected performance drop of 2% over 5 years could result in a loss of 70k Euro.



Accurate irradiance measurements with pyranometers

How many pyranometers?

The number of pyranometers, and their placement on a solar plant, is a subject of discussion in the utility-scale solar power market. Internationally accepted guidelines such as the Project Developer’s Guide, Utility-Scale Solar Photovoltaic Power Plants (IFC 2015) and the recent standard IEC 61724-1:2017 Photovoltaic system performance monitoring provide recommended minimum numbers of pyranometers for different plant capacities.

PV plant size	Min. number of SMP10 pyranometers	
	Horizontal	Plane of array
< 5 MW	1	2
5 to 40 MW	2	4
40 to 100 MW	3	6
100 to 200 MW	4	8

However, these minimum numbers do not take into account:

- Differing environmental conditions across a large solar park; such as near or far shading effects, surface reflections, micro-climates, cloud transit times and dust accumulation (soiling).
- Plant design division into subsystems; strings, MPPs, inverters and differences in panel orientation & tilt.
- Redundancy; continuous measurement during service and calibration of pyranometers and backup in case of faults.

In general, substantial (environmental or design) deviations within a solar park need to be covered by separate, representatively positioned, pyranometers.

Maintenance

Pyranometers require some maintenance to maintain accurate measurements and this should be incorporated in every O&M planning schedule. In particular, the dome needs regular cleaning and the alignment (horizontal or plane of array) must be checked after cleaning. Recalibration is generally recommended every 2 years.

Irradiance measurement chain

Just fitting a high quality pyranometer is not enough, the entire data collection and analysis process must be robust and secure:

- Use Secondary Standard pyranometers for low measurement uncertainty.
- Sampling and logging intervals of the irradiation data:
  - sample every 1-5 seconds
  - log the average of the samples every 1-5 minutes, based on the sampling rate
- Use a good quality scientific data logger for unamplified pyranometers (CMP10).
- Record the Modbus® digital data of Smart pyranometers (SMP10).

Use statistically sound data analysis in the plant monitoring software, such as in SynaptiQ.
High quality site-specific solar irradiance data is the key to meaningful plant monitoring.


When irradiance matters.
Image Credit: NASA