

# Whitepaper

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6 Key influences that determine  
PV performance ratios



# 6 Key influences that determine PV performance ratios

Solar engineering, procurement and construction (EPC) companies are the members of the solar energy industry that build, and often maintain, power generation projects. Installations range in capacity from relatively small rooftop arrays to multi-megawatt utility-scale plants.

Yield, availability and performance ratio (PR) are the most common performance indicators for solar power parks. Performance ratio is particularly interesting since it relates the theoretical power output of the system design to the power actually produced.

## Performance ratio definition

The performance ratio is the ratio between the final (actual) yield of a solar power generating system and its reference (design) yield over a defined period of time:

$$\text{Performance Ratio} = \frac{\text{final yield}}{\text{reference yield}} \times 100\%$$

Performance ratio is typically calculated over a year, since this filters out daily and seasonal influences, and is an important quality indicator of a solar power system: the quality of components, design, installation and maintenance.

Although the formula for PR looks nice and simple, the definition of final yield and reference yield is food for discussion. Most software tools for solar plant monitoring allow the user to choose several definitions and constraints for the calculation.

The final yield of AC power generated is easily measured with high accuracy at the grid connection.

The reference yield is the theoretical power produced by irradiance on the PV panels; the solar energy received by the panels multiplied by the efficiency of the conversion to electrical energy. PV panel efficiency is the dominant factor as, typically, 15 to 20% of the incoming energy is converted into electricity.

The conversion efficiency of silicon PV cells is temperature-related, higher temperatures reduce the power produced for the same irradiance. Therefore, the panel temperature should be taken into account, resulting in a temperature corrected performance ratio. For the reference yield, accurate local measurements of irradiance and temperature are of key importance.



## How to use performance ratios?

Performance ratios (if defined and monitored in the same way) can be used to compare solar plants at any locations: a well-designed, -installed and -maintained solar park in the Arctic could have a better PR than an averagely designed and installed solar park near the Equator (although the latter receives far more energy from the sun).

Due to growing expertise in design and maintenance, and improvements of technology over the years, the PR of well-performing PV solar plants has risen from less than 70%, for systems built before 1995, to more than 80% for recent installations.

Time period	Performance ratio (%)	
	Range	Typical value
Before 1995	25 to 70	65
1995 - 2010	65 to 80	70
2010 and later	75 to 90	82

Based on *Monitoring of photovoltaic systems: good practices and systematic analysis* (PVSEC 2013) and *Project Developer's Guide, Utility-Scale Solar Photovoltaic Power Plants* (IFC 2015).



Performance ratio plays an important role throughout all phases of the development and operation of a solar energy park, as shown in this table.

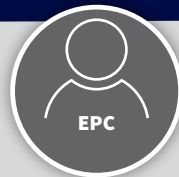
Solar park phase	PR importance	Remarks
Site prospecting	Medium	The estimated performance ratio is an indicator for the potential profitability of a solar plant.
Design	High	Excellent solar plant design optimises yield and reduces losses, resulting in a high PR.
Installation and commissioning	High	Following the design scheme as closely as possible is key to reaching the designed reference PR. An initial operational period, from several weeks to months, is used to calculate the commissioning PR. From this a contractually agreed target PR is derived (allowing for errors and repairs to be within the agreed value).
First years of operation (2-5)	High	This is the proving period, during which the final performance ratio of the plant is determined.
Steady operation ( 20-25 years)	Medium	Yield is very important during this period; however, PR is used to determine the quality of the operations and maintenance (O&M) procedures.
Refunding, re-investment	Very high	PR is a quality indicator of design, materials, installation and maintenance of a solar park.
Refurbishment	High	If yield is below expectations and PR is decreasing, a business case for refurbishment (e.g. replacement of inverters, cabling and/or panels) can be made.

**“Performance ratio is an important tool for all the main stakeholders in the utility solar energy market”**



**Investor**

By selecting a portfolio of solar parks with high PRs, and selecting O&M parties with a track record of delivering high PRs, investors on the secondary market can reduce risks on one hand and secure revenues on the other.



**EPC**

By showing high performance ratios after the initial building, commissioning and operating period, EPCs can demonstrate their ability to design and construct well-performing solar energy plants. Such plants will generate higher selling prices on the secondary market, and reduce future risk for the buyers.



**O&M provider**

By maintaining yield and availability at high levels at modest costs, O&M parties can show their added value in optimised operating and maintenance policies. A high performance ratio is a reflection of the quality of their work.

Some constraints should be borne in mind:

Excluding periods at the start or end of the day where the inverters are switched off, so that only the ‘operating day’ is taken into account for power generation, should only be done if this was also part of the design reference specification.

Excluding malfunctioning parts of the solar park (due to faults) makes the PR look better, but there is no incentive for the O&M party to rapidly resolve the problem that causes the unavailability.

Possible differences in definitions of performance ratio by various parties involved.





# What influences the performance ratio?

*There are many factors affecting or determining the performance ratio of a solar energy project and the 6 key influences are described next.*

# 1

# Environmental factors

The environment surrounding a solar energy plant is important for the performance ratio: each location has its own micro-climate in terms of irradiation, sun elevation paths, shading (by mountains, woods, wind turbines, clouds), temperature ranges, precipitation, wind, pollutants and soiling.

These environmental factors are very important for the prospecting and design phases. Satellite instrument records and interpolated meteorological data can provide historical information covering 10 years or more. This information is an input for solar energy resource models, but it is of variable quality and spatial resolution. Local ground-based measurements over at least a year are highly recommended to verify, and adjust, the long-term data for the specific site. Based on these and the historical data sets the suitability of the site for a solar park (prospecting) can be analysed.

Most environmental factors are naturally occurring and cannot be changed, but they are crucial factors for a good business case during prospecting and they heavily influence the plant design and the likely maintenance required. During plant operation accurate measurement of the environmental factors is key to determining the performance ratio. A mean annual temperature of 2°C higher than the value used in the reference calculation drops the PR by 1%.

By using accurately measured irradiance and the temperature corrected performance ratio, two of the critical environmental factors for PV systems are taken into account, both for the reference and final yields. This also enables PR to be used over shorter periods, typically monthly, as it is less sensitive to seasonal fluctuations.

Soiling and precipitation (especially raindrops) strongly influence the PR. Accumulation of dust, sand, biological deposits (algae, moss, bird droppings) and air pollution have a direct effect on the power output of a solar panel. The local soiling conditions must be taken into account in all phases of a solar plant's life. However, rainfall often has a positive effect by washing off deposits. Optimised cleaning schemes boost the PR and minimise cleaning costs.

The following environmental factors should be measured, with a degree of accuracy and traceability, to calculate a reliable performance ratio:

***Radiant flux (energy directly from the sun and diffusely from the sky) in the plane of array (parallel to the PV panels) and horizontally (for comparison across data sets)***

***PV module temperature, for the temperature corrected performance ratio***

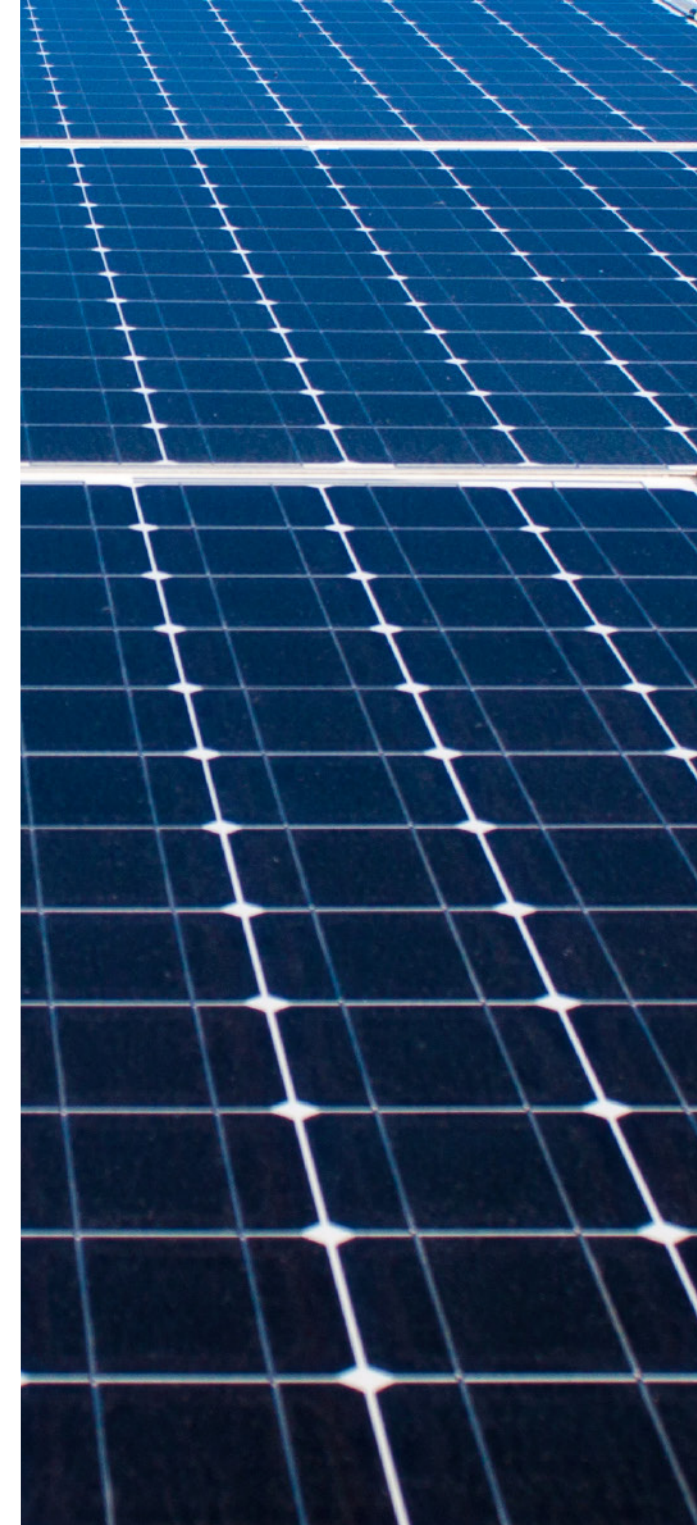
***Ambient air temperature to correlate with, and predict, the panel temperature as a result of the environmental conditions***

***Wind speed and direction for calculating a chill factor (cooling of the panels) that boosts the panel output and also dries dew and raindrops***

***Soiling ratio (SR) for an estimate of the lost yield***

***Precipitation in the form of dew, rain, frost, snow, hail - typically included in the SR***

***Relative humidity to predict dew and frost incidence***





# 2

# Design and component selection

## The design phase can make, or break, the performance of a solar energy generating plant:

Selection of components of a quality suited to the operating environment and the level of performance required. PV panels, support structures, cables, inverters, transformers and monitoring equipment differ; so a selection of components is made according to the circumstances of the plant. For example, high wind speeds, sand storms, snow, regular dew, salt build-up near the coast, low temperature dependency in hot areas, corrosive pollutants in industrial areas.

Often, key stakeholders have a list of preferred 'bankable' suppliers (a short list of companies and products with proven quality, performance, reliability and lifetime costs). Better quality and performance products will, in general, provide a more reliable long-term performance ratio, with lower uncertainty, that is acceptable to the key stakeholders.

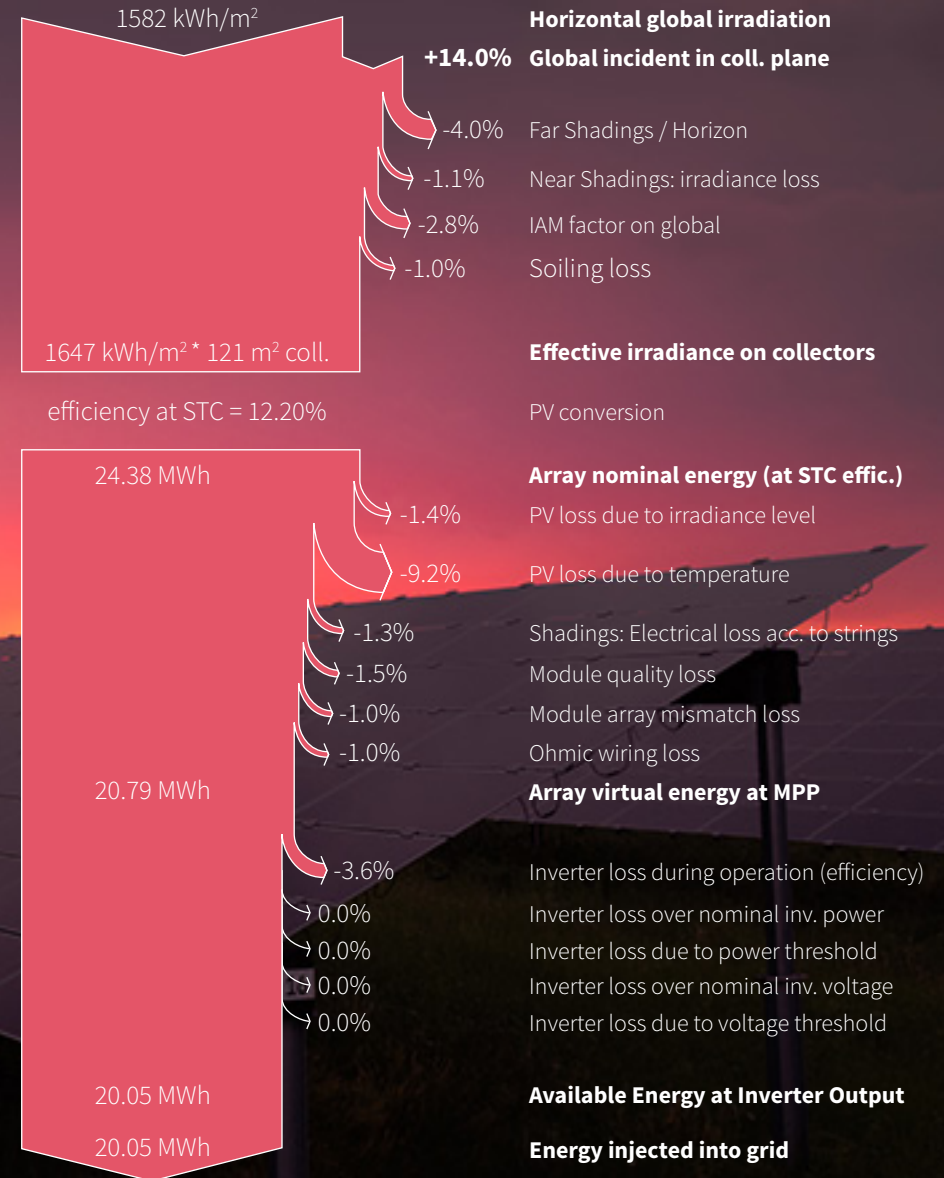
The terrain and the immediate environment often dictate the optimal lay out of the solar plant. A wide, flat plain is much simpler than an undulating, hilly and rocky topography. Woods, hills, mountains or man-made structures may cause shadows at certain times, influencing the actual yield. Good design minimises these effects.

The solar elevation angles (declination) at the location during the year, and the seasons at which the optimum power output are required, determine the optimal tilt angle of fixed PV panels and the distance between the rows (due to shading by the row in front). However, a steeper panel tilt generally reduces soiling and the associated yield loss and the need for cleaning, and this should be taken into consideration.

Good electrical design minimises power losses. Direct Current (DC) produced by the PV panels is converted to Alternating Current (AC) by the inverters and stepped up to grid voltage by transformers.

A number of software packages are available providing solar plant design and simulation tools with guidelines for plant design and performance ratio optimisation.

## Loss diagram over the whole year



# 3

## Installation and commissioning

Correct plant installation on the site, staying as close as possible to the optimised design, contributes enormously to the final PR approximating the reference PR. There are many cases in which the installed panel tilt or row spacing deviate significantly from the design. In such cases, the final PR will not achieve the planned reference PR with a subsequent impact on the business case and return on investment.

Regular (independent) oversight of the construction process, focusing on materials, material handling, physical lay-out and electrical installation, will help to avoid modifications or re-construction in the commissioning and acceptance phases of the plant.

The contractually agreed target performance ratio (sometimes called the Guaranteed Performance Ratio) is often slightly lower than the final PR, to allow O&M parties to correct faults and restore interrupted operation. A checklist for this is provided by the 2015 International Finance Corporation Project Developer's Guide, Utility-Scale Solar Photovoltaic Power Plants.

# 4

## Ageing

All the important components of a solar power plant are subject to ageing, and therefore contribute to a lower performance of the plant over time: PV panels, cables and connections, inverters, etc.

There are two ways of dealing with this ageing of materials in the performance ratio:

- Take ageing into account at the contract stage to allow for a decrease in PR over time, within specified boundaries.
- Use a maximum ageing rate correction in the calculation of the PR such that the reference yield decreases over time, making the PR stable.

Studies such as the Compendium of Photovoltaic Degradation Rates (NREL 2015) show that performance of PV panels commonly reduces by 0.5-1% per annum, although cases do exist with hardly any degradation after 20 years.

Inverters are a known source of faults on solar plants. When replaced by another type of inverter, typically after 10-15 years, the new model will usually have better specifications and the contractually agreed performance ratio should be reviewed.

### Ageing is inevitable in a solar plant:

- New solar panels have a nominal power output and efficiency but there is a variation between panels of the same model. Some may generate up to 5% more power than others and this imbalance tends to increase over time.
- The efficiency of inverters depends on input power, operational temperature and the design and quality of the DC to AC conversion electronics. As components age, the efficiency of the inverter will decrease over time.
- Connections and cabling degrade over time, particularly due to environmental exposure, and cause conduction losses.
- Broken or shaded panels, broken inverters and broken cables will cause parts of the solar plant to contribute no power until repair or replacement, causing yield loss and lowering the performance ratio.

The way that ageing losses are taken into account in the calculation of the performance ratio over the lifetime of the plant influences the business case and the return on investment.



# 5

# Maintenance

Maintenance of a solar power plant involves costs. However, those costs can be used to optimise profits. In the past, it was suggested that solar plants could operate without maintenance; nowadays, operations and maintenance (O&M) is regarded as serious business, contributing to the optimal performance of solar parks. Organisations such as SolarPower Europe, the Solar Energy Industries Association and the SunSpec Alliance have released guidelines for optimal maintenance strategies.

Two types of maintenance are distinguished

## Preventive maintenance

Planned actions to avoid corrective maintenance; such as changing inverter air filters, grass cutting before it causes shadows on the panels, cleaning panels to avoid heavy soiling, and the inspection, cleaning and calibration of environmental monitoring instruments.

## Corrective maintenance

Unplanned actions to restore normal operation after an unscheduled interruption. Examples are the replacement of broken panels, cables or connections, repair or replacement of faulty inverters or damaged support structures, and replacement of malfunctioning instrumentation.

Preventive maintenance has a regular schedule with known downtime and impact on power generation; whereas, corrective maintenance may require immediate action (depending on the severity of the problem). Especially for unmanned, distant sites, good preventive maintenance minimises corrective maintenance and it is usually cheaper.

Remote asset monitoring tools, supported by high quality data aggregation and analysis, assist O&M parties in optimising yield and are key to achieving high performance ratios.



# 6

# Measuring irradiance & other factors

The incoming solar radiation incident on the PV panels is the most important parameter to calculate the performance ratio. Irradiance measurements must be performed well to calculate a useful PR with a known uncertainty. International Standard IEC 61724-1:2017 Photovoltaic system performance monitoring recognises that this is crucial and specifies the requirements for the measurement of global horizontal irradiance (GHI) and irradiance in the plane of array (POA, the same orientation and tilt as the solar panels).

Irradiance can be measured in several ways

## Pyranometer

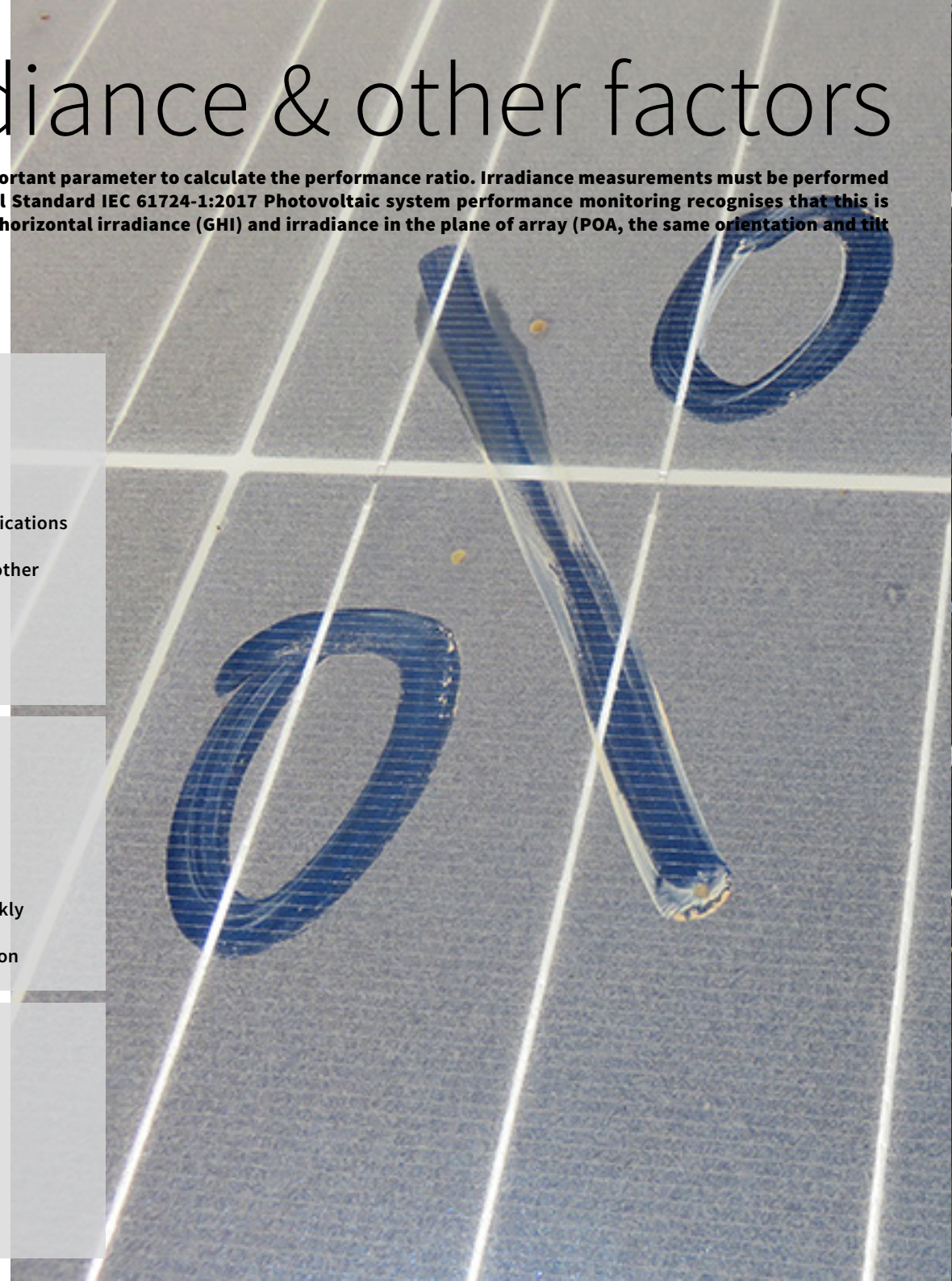
- Performance classifications defined in ISO 9060:1990
- Secondary Standard types recommended for most solar energy applications
- Measures all solar radiation from ultraviolet to near infrared
- Provide the GHI data from ground-based meteorology, climate and other monitoring networks used in solar energy resource models
- Rugged construction with long lifetime
- Can be used to measure GHI or POA irradiance
- Needs regular cleaning and calibration

## Reference cell

- Only measures a part of the solar radiation spectrum
- Should be of the same cell type as the PV panels in the plant
- Variable quality of design and materials, can degrade relatively quickly
- Can be used to measure GHI or POA irradiance
- Needs regular cleaning (more often than pyranometer) and calibration

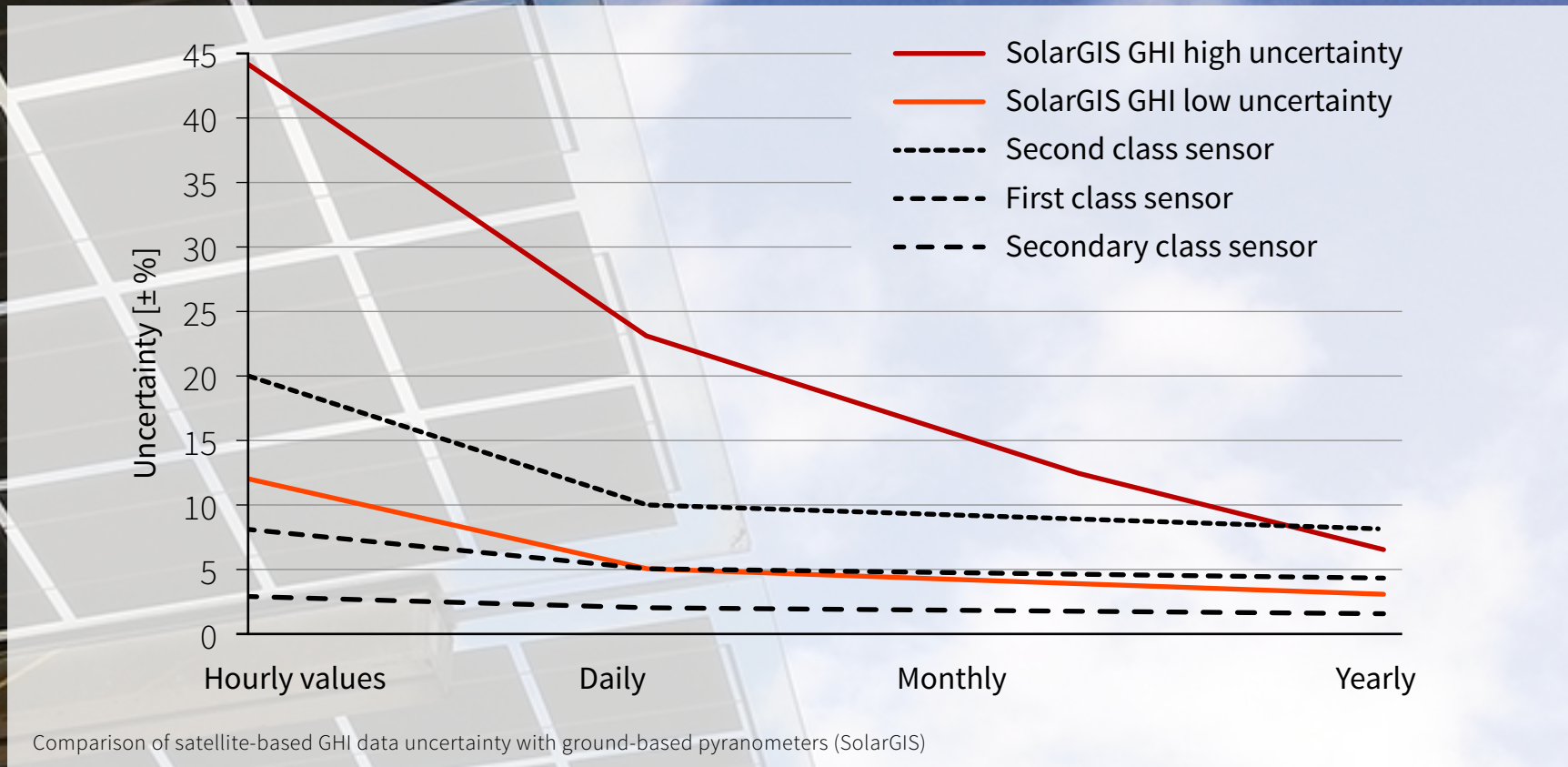
## Satellite data

- Coarse spatial resolution, typically 3 x 3 km.
- Not available in real time and no useful data for cloudy periods.
- Measures GHI only, large uncertainty for derived POA irradiance.
- Easy access, high availability, requires a subscription fee.





The graph illustrates why satellite data can only be used over relatively long time periods for performance ratio calculations. Data from a good Secondary Standard pyranometer can be used in real time. The measurement uncertainty of the daily total irradiance is typically around 2%, but can be down to 1% for the best models.





Back panel temperature measurement is known to be problematic, due to adhesives becoming less thermally conductive and failing with age. IEC 61724-1:2017 prescribes how to measure panel temperatures in detail.

For other environmental measurements (wind, humidity, etc.) a large variety of equipment exists at a wide range of price and performance points.

Soiling of the glass of PV panels is one of the major issues in the rapidly expanding solar energy market, with the attendant loss of efficiency and reduction in performance ratios. The problem is recognised and addressed in IEC 61724-1, which includes soiling ration (SR) as one of the parameters to be measured in a high accuracy monitoring system. Soiling is entirely dependent upon the location and the environment. For example, in Qatar the average soiling rate is 0.5% per day (excluding extreme sand-storm events).

Cleaning PV panels costs money, but so does the loss of output due to soiling and the reduction in performance ratio. The SR can be translated into yield loss in real time, enabling the plant operation and maintenance staff to know when a critical level of soiling is reached and it has become necessary to start cleaning procedures.

### **Choose the performance ratio that fits your needs**

Performance ratios for any individual solar energy project come in a variety of forms, theoretical and actual, related to different phases of the project; design, installation, commissioning, contractual agreements and operational. Be clear which PR you are referring to in communications with other parties and how it is defined and calculated, particularly with reference to the 6 key influences discussed in this article.

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