

HOW TO IDENTIFY A RELIABLE YIELD ASSESSMENT

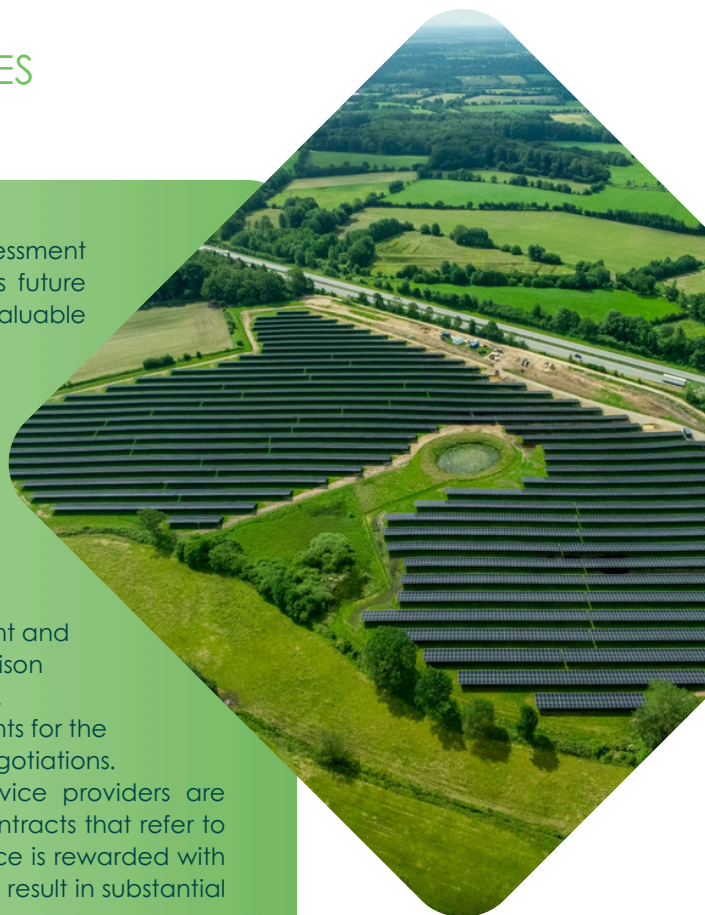


GREENTECH
WHITEPAPER

A RELIABLE PV YIELD ASSESSMENT SERVES ALL PARTIES INVOLVED

When developing a solar park or PV system, the yield assessment plays an important role: it is used to determine the system's future performance and provides the various stakeholders with valuable information about the project:

- Project developers and general contractors use it to determine the general yield potential of a specific site or area. They can assess whether implementing the project and potentially selling it at a later stage would be commercially viable for them.
- For banks and investors, it provides a well-founded basis for deciding whether to finance the project.
- For the future operator, it serves as a basis for the investment and as a performance benchmark, enabling a specific comparison between the target and actual performance of the system.
- In a sales process, both parties often submit yield assessments for the project in question and use them as a basis for the sales negotiations.
- Service providers such as EPC contractors or O&M service providers are increasingly providing performance guarantees in their contracts that refer to the results of the yield assessment. While better performance is rewarded with a bonus, failure to meet the guaranteed performance can result in substantial contractual penalties.

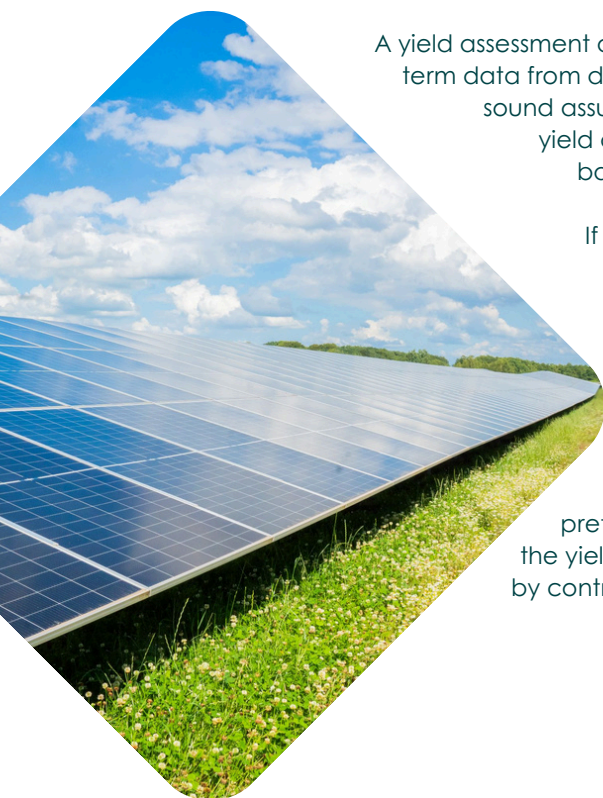


PRIMARY OBJECTIVE OF THE YIELD ASSESSMENT: A REALISTIC RESULT FOR THE EXPECTED YIELDS

A yield assessment always involves some uncertainty. That is why it is important to use long-term data from different sources, consider relevant factors and base the assessment on sound assumptions. This helps create a realistic estimate of the system's expected yield and provides everyone involved in the project with a reliable, impartial basis for decision-making.

If forecasts are too conservative, no investor or lender may be found for the project. If, on the other hand, the calculations are too optimistic, there is a risk that the project will ultimately fail to meet expectations and that the investment costs cannot be recovered. This would not benefit any of the parties involved.

Yield assessments therefore also always take potential standard uncertainties into account. These include, for example, deviations in meteorological conditions or uncertainties in the professional interpretation of the data and the simulation software. The P50 value indicates the yield that the system can achieve with a probability of 50%. The P90 value, by contrast, indicates the yield that will be exceeded with a probability of 90%.



WHICH PARAMETERS CONTRIBUTE TO THE MOST REALISTIC POSSIBLE YIELD FORECAST?

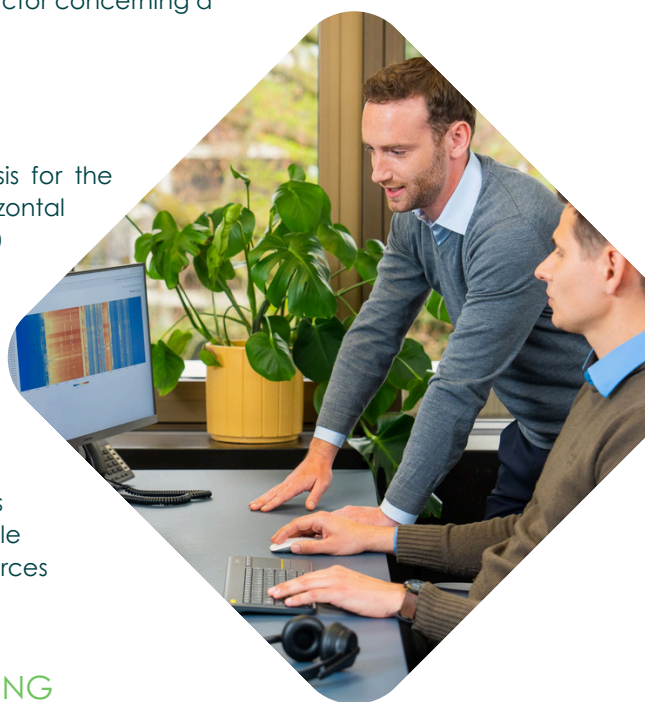
The future yield of a photovoltaic system is influenced primarily by the meteorological conditions at the site — in particular solar irradiation and temperature — as well as the existing topography, potential shading objects and the technical design, including the components used.

All potential site factors and technical framework conditions must therefore be identified precisely and incorporated when preparing a PV yield assessment. The first step often involves recording all the conditions on site as part of a site and route analysis. Drone technology has proven effective for this purpose. A drone survey and the creation of a 3D terrain model produce a precise aerial image of the site, including elevations and irregularities. All shading objects are represented according to their position and dimensions. This makes it possible to create a precise 3D scene for shading simulations in the PVsyst software at a later stage. At the same time, it reduces the scope for later discussions — for example, about tree heights — in discussions with investors or during negotiations with the EPC contractor concerning a performance ratio (PR) guarantee.

SOLAR IRRADIATION AT THE SITE

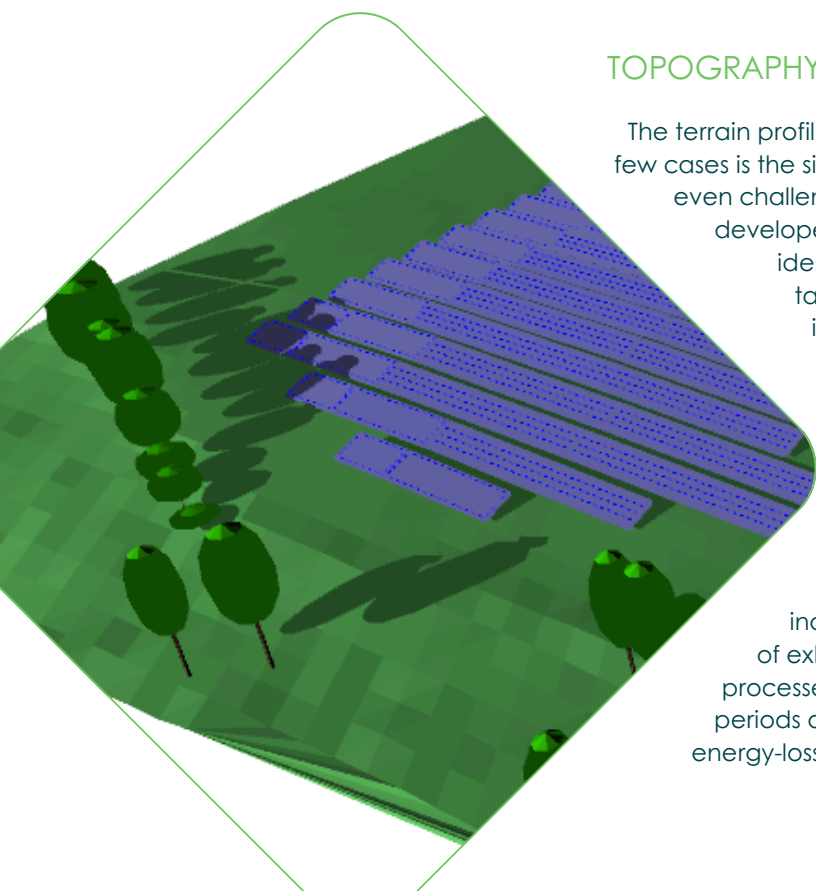
Determining the future solar irradiation at the site forms the basis for the assessment and the subsequent evaluation. As a rule, historical horizontal global irradiation data, measured in kWh/m², from the past 15 to 20 years are used for this purpose. These data are collected and provided by various reputable data providers. Solar irradiation is measured, among other ways, by ground-based measurement stations in the surrounding area or by satellites for the location in question.

As the different measurement methods can result in irradiation differences of several percentage points, data from various sources are used and carefully evaluated to ensure the most reliable possible yield estimate. A weighted average is then calculated from the sources considered reliable for the site.



TOPOGRAPHY / SHADING

The terrain profile of the site is also relevant to the future yield. In very few cases is the site a flat area without any shading objects. However, even challenging, uneven terrain with surrounding slopes can be developed with an efficient PV system if the planning process identifies potential sources of interference precisely and takes them into account in the subsequent design. This includes not only the shadows cast by slopes or trees; the immediate surroundings of the site should also be examined closely. For example, high-voltage pylons or the rotor blades of nearby wind turbines can cast shadows. Nearby factories can cause shading not only through their chimneys but also through emissions of smoke under certain wind conditions. Motorways and railway lines, as well as nearby agricultural operations or industrial companies, can also cause soiling in the form of exhaust fumes, airborne pollen and small particles from processed materials. In areas with heavy snowfall, expected periods of snow cover must also be considered as a potential energy-loss factor.



SYSTEM DESIGN

In addition to the site conditions, the selected system design also plays a decisive role.

MECHANICAL DESIGN

The positioning of the modules determines how much solar irradiation reaches the PV generator.

At what **tilt angle** are the modules installed? The tilt angle affects the irradiation on the module surface, the inter-row shading, the space required and the cleaning requirements. Under certain conditions, a greater tilt angle can increase the energy yield. However, it generally also requires greater row spacing and more land. A lower tilt angle allows for denser site coverage, but may impair the self-cleaning effect provided by rain. The optimum tilt angle must therefore be determined for each site and project.

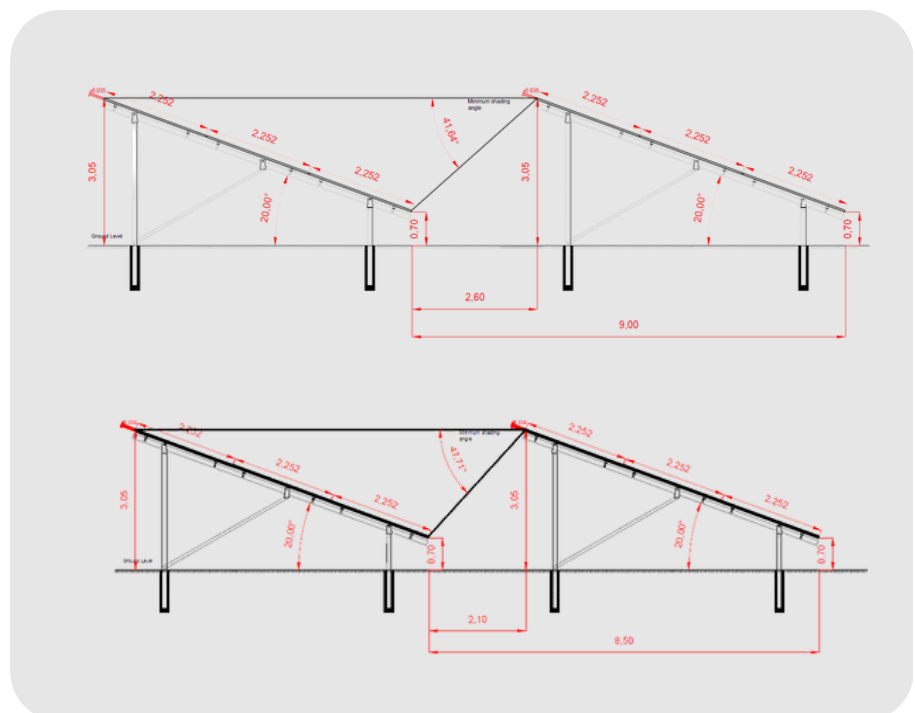
Large-scale ground-mounted systems today predominantly use bifacial modules. In addition to direct irradiation on the front side, these modules can also use reflected and diffuse light reaching the rear side. The level of additional energy yield depends, among other things, on the ground conditions and their reflectivity, the module height, the row spacing and the system configuration.

As an alternative or in addition, single-axis tracking systems can be used. They change the tilt angle of the module rows over the course of the day, thereby aligning the modules more effectively with the sun. In combination with bifacial modules, they can further increase the energy yield. A process known as back-tracking reduces the mutual shading between the module rows.

Single-axis tracking systems can also offer advantages in agrivoltaic systems. The movable module rows make it possible to control the shadows cast and the amount of light reaching the agricultural area more precisely. They can also be designed to allow the land to be cultivated and agricultural machinery to pass through. Whether trackers, a fixed-tilt mounting structure or a vertical system is the most suitable solution depends on the crop being grown, the use of the land, the site conditions and the economic viability.

What **orientation** was selected for the modules? This is also referred to as the azimuth angle. An angle of 0° describes the optimum south-facing orientation. Positive values (+) indicate an orientation towards the west, while negative values (–) indicate an orientation towards the east. A system facing exactly south produces the highest yields. Depending on the site, however, a different layout may be more advantageous if it allows more capacity to be installed.

Row spacing is also relevant to the yield: the closer the module rows are placed, the greater the installed capacity and the absolute energy yield. However, a smaller distance between the rows also increases self-shading and reduces the specific yield. Planning must therefore determine precisely which row spacing will make the most efficient use of the available space in terms of yield.





SYSTEM DESIGN

ELECTRICAL DESIGN

The electrical design describes how the electrical components are interconnected on the direct current (DC) and alternating current (AC) sides. The yield calculation must therefore take into account how many modules are connected in series to form a string and how many strings are connected in parallel to a DC combiner box or directly to the inverter.

It is also crucial to consider how much module capacity is connected to each inverter. This so-called DC/AC ratio determines the level at which the inverter is loaded and whether high solar irradiation causes the inverter to limit the DC output. This is known as clipping and results in energy losses. On the other hand, loading the inverters more heavily can also lead to higher yields during periods of lower solar irradiation.

COMPONENT PROPERTIES

Components from different manufacturers also have different characteristics that affect the system's energy yield. Depending on the operating conditions and external meteorological influences, output, losses and efficiency vary. The energy yield assessment must therefore determine how the components selected for the system respond under different conditions. These include, among other things:

- the behaviour of the modules under high and low solar irradiation: is an independent test report available for the low-light behaviour that confirms the manufacturer's specifications?
- the reflection behaviour of the module (IAM);
- changes in module or inverter output at different ambient temperatures and the corresponding changes in module or equipment temperature.

Natural performance losses also affect the yield of a PV system. All crystalline modules are subject to light-induced degradation (LID). This effect causes a slight but permanent initial reduction in module output when the module is first exposed to sunlight.

Module manufacturers provide information on the precise characteristics of their components in files for simulation applications (.pan files). These files are imported into the simulation software, stored there and used in the yield simulation. However, the assessor should always question this information critically and check whether it is plausible. Independent inspection reports or tests by independent laboratories can also be helpful; these can often be obtained through the manufacturers as well.

Over time, the assessor builds up a broad database of the characteristics of many components from the manufacturer files and can compare them with one another as required.

Corresponding files are also provided for the various inverters (.ond files). Among other things, they contain information on efficiency under different conditions and behaviour when temperatures deviate from the norm. Transformer data sheets include, resistance losses relevant to the yield — so-called copper losses — as well as losses caused by magnetisation and eddy currents, known as iron losses.

The system cabling also plays a role in the yield. Certain materials, as well as long cables and particular cable cross-sections, cause voltage losses on both the DC and AC sides and therefore reduce the yield. These losses must be calculated accordingly and included in the simulation.

INFORMATION BOX:

YIELD SIMULATION VS. YIELD ASSESSMENT

A yield simulation produces results — for example, outputs generated by simulation software such as PVsyst. An assessment supplements these results with explanations of specific inputs and derivations, as well as a critical evaluation. It explains, for example, which conditions and assumptions led to the selection of particular settings in the simulation software. The results are also assessed and interpreted in detail.





GRID OPERATOR REQUIREMENTS

An important aspect of preparing the yield assessment is complying with the applicable grid code and taking the project-specific requirements of the relevant grid operator into account. If the project-specific requirements are not yet available, valid assumptions must be made on the basis of the applicable grid code.

When designing a photovoltaic system, the provision of reactive power must also be considered. In AC circuits, reactive power is unavoidable and is caused by physical effects. The desired or required power factor ($\cos(\varphi)$) specified by the grid operator plays a decisive role here: it determines the level of apparent power and therefore the additional inverter capacity required.

The power factor can be used to neutralise a phase shift already present in the grid and to influence the voltage in AC networks. The PV yield assessment incorporates the system's active power in specific operating conditions and also includes the provision of reactive power in its calculations.

A GOOD YIELD ASSESSMENT ALSO CHALLENGES THE EXISTING SYSTEM DESIGN

The yield assessment is usually based on an existing system design with predefined parameters. If the simulation and the assessor's subsequent evaluation suggest that a modified design could further improve the yields, this should be discussed with the system designer and the project developer or investor and implemented wherever possible.

YIELD ASSESSMENT AT A GLANCE

A GOOD YIELD ASSESSMENT IS

- ... prepared objectively in order to produce the most realistic possible result;
- ... based on comprehensive and detailed data collection for the greatest possible accuracy;
- ... analysed and evaluated on a sound technical basis for maximum robustness;
- ... documented coherently to ensure the greatest possible transparency and traceability for all parties relying on it.



ABOUT GREENTECH

As an integrated solar and energy storage specialist, greentech supports projects from development through to operation. Through its Engineering & Technical Advisory division, greentech provides comprehensive technical expertise for PV systems, battery energy storage systems and substations — from system design and grid connection through construction and acceptance supervision to technical due diligence and operational optimisation. In this way, greentech combines technical expertise across all phases of a project.

Note: This white paper provides a general and simplified overview of the preparation of yield assessments for photovoltaic systems. The influencing factors and work steps presented are examples and do not claim to be exhaustive. Depending on the project, site, system design and data basis, other aspects, assumptions and checks may be relevant that are not covered here or are not discussed in detail. The content does not replace a project-specific yield assessment and does not constitute legal, tax, financing or investment advice.

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