BIFACIAL DESIGN GUIDELINE

INTRODUCTION

Bifacial modules offer the opportunity to provide additional electrical power from the light which reaches them from the rear side and therefore can achieve a power and yield increase of about 10 % or even more.

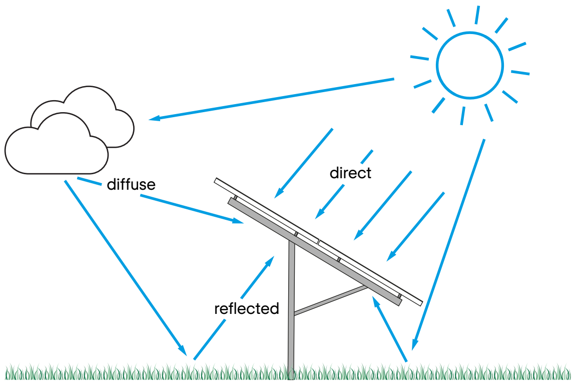

Figure 1: Additional power from rear side: drawing showing front and rear side irradiation.

The additional yield leads to a reduction of LCOE (Levelized Costs Of Electricity, e.g. in $ per kWh), depending on additional costs which might arise from additional efforts for an optimum PV system layout.

Basically, the more light gets into the solar cells the more electricity can be produced. So additional light from the rear side can be transformed into additional power. However, PV cells and modules used to block light from the rear side so both and cell and module technology has to be adapted to make modules transparent from the rear side. This includes some basic decisions concerning the product design: cell rear side layout, transparent rear side foil or rear glass, junction box position and design and finally framed or frameless. All of these aspects have not only an effect on the module's ability to collect additional light from its rear side but also on other important product features like available mounting options and load capabilities.

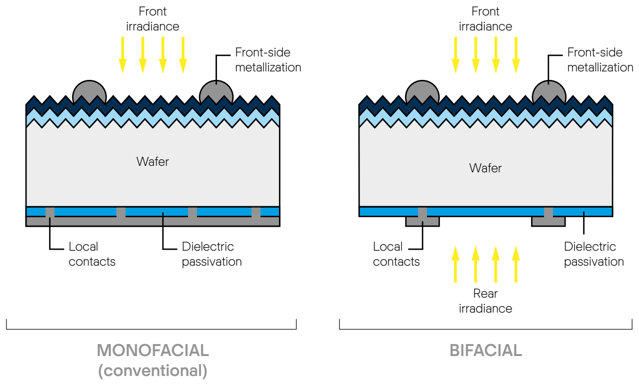

Figure 2: Bifacial cell schematic - Bifacial vs. Monofacial

The frame allows for all usual mounting options with bolts and clamps which available with a standard ("monofacial") module, too. Although there is no middle-rail in Q CELLS bifacial modules, a tracker mounting is possible with according "Hi-rise" mounting clamps or rails. Additionally, a white grid between the cells increases the front side power of the module.

Note: The white grid does not have an effect on the rear side power of the module.

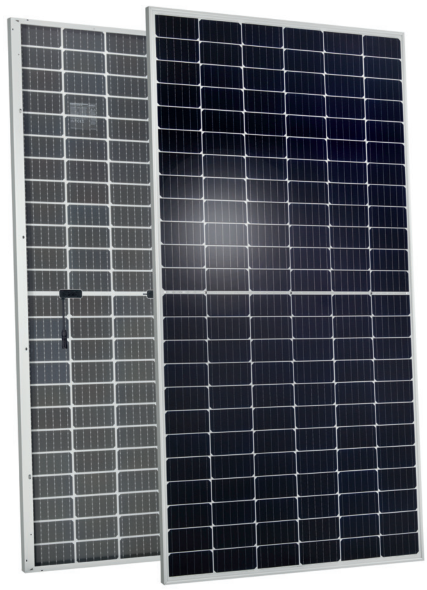

Figure 3: Bifacial module (rear and front side).

The basic idea of a bifacial module is quite simple: To collect additional light from the rear side. Nevertheless, compared to monofacial technology, the system planning of a bifacial system requires more factors to be considered and therefore comes up with some challenges. Especially there are some system concepts which do not make sense with bifacial modules (e.g. Roof-top and Flatroof with east-west oriented modules, see figure 4) because there is just no light to the modules' rear side in these cases.

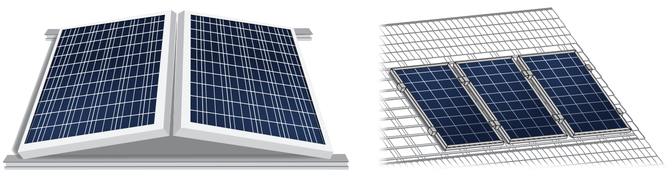

Figure 4: Examples of mounting options for which bifacial modules do not make sense.

On the other hand, measures in order to get more light behind the modules (increased row-to-row distances, increased installation heights, increased ground albedo, ...) will create additional costs which have to be overcompensated by the achieved electricity yield. This basically means a new approach for the system optimization of bifacial PV systems.

BIFACIAL GAIN - BIFACIAL SYSTEM POWER

Unfortunately, there is not yet a general standard how to define a nominal power of bifacial modules. Because the additional irradiance from the rear side depends on a lot of factors even for a certain front side irradiance, the actual module power will vary over a rather wide range. The nominal power of the module (nameplate power) of Q CELLS bifacial modules refers only to the front side power of the module.

However, the actual power of the module will be accordingly higher which has to be considered in the system design (e.g. lower DC / AC ratio than for a monofacial system). The module data sheet shows the expected electrical values under STC with additional irradiance from the rear side ("Bifi100" and "Bifi200") according to IEC 60904-1-2.

BIFACIAL DESIGN GUIDELINE

Higher total irradiance on each cell also leads to a higher effective V_{OC}, which has to be considered for the string sizing. The effect will be between 1% and 2% and therefore its influence is small (especially it is smaller than the typical measurement tolerance of V_{OC} given in the data sheet). However, in any case the string sizing remains in the judgement of the system engineer. There are other aspects of system design to be considered when changing from a monofacial system design towards a bifacial system design, like e.g. comparably higher ohmic losses in the cables due to increased currents. Such additional losses of course should be taken into account when talking about the bifacial gain. Nevertheless in some cases it could be feasible to switch to the next higher cable diameter. Generally, system design for bifacial systems should consider higher currents compared to standard monofacial systems.

The increase of the electrical (STC) power of a module depends on irradiation onto the rear side of the module which in turn depends on a huge heap of system parameters and will also vary over time depending on the sun height and weather conditions. For both, bifacial and monofacial modules, the important system output parameter is the yield of electricity (in kWh per year). Also with standard monofacial modules the yield of electricity is determined by the module power but also depends on system parameters like tilt, row distance and of course irradiance, i.e. geographic location and weather.

With bifacial modules these dependencies become more complex because the rear side irradiance in turn depends on the system parameters. E.g. the distance between the rows of modules (the “pitch”) strongly influences the amount of light which can be “used” by the rear side.

Therefore the optimization of the yield of electricity (over one year or system lifetime, e.g. 25 years) of a bifacial system requires more careful planning than with standard monofacial modules. That’s why in the following section the most important parameters and their effect on the system yield shall be shown in an overview.

Note: This overview cannot replace a detailed system planning by the installer or an etxernal system engineer. In some cases the dependence of the yield of electricity on a certain parameter may even change its sign depending on the actual value of other parameters.

SENSITIVE SYSTEM PARAMETERS: ESTIMATION AND OPTIMIZATION OF BIFACIAL GAIN

As long as only front side power defines the the module's name plate the usage of bifacial modules leads to an increased energy yield for equal nominal power, i.e. a higher specific yield and performance ratio is to be expected.

a. Design Parameters with Influence on Bifacial Gain

Note: In this section only those system parameters are introduced which have a special influence on bifacial gain. Terrain slope and associated system azimuth different from south direction for fixed tilt systems are not considered here because these are similar for bifacial and monofacial systems.

Module Bifaciality Factor

Definition: The bifaciality factor (BF) is the ratio between the power measured on the front side and the power measured on the rear side, both under STC conditions (i.e. 1000 W/m² illumination etc.).

Note: For a certain bifacial gain, a high (front side) module power leads to an accordingly high rear side yield.

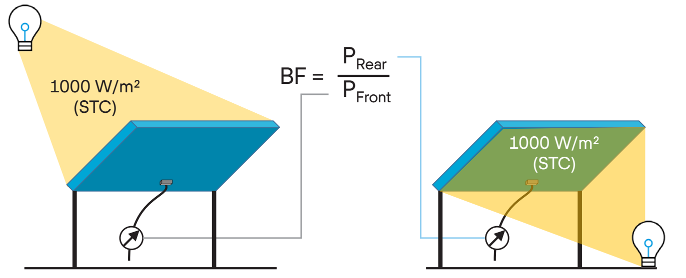

Figure 5: The Bifaciality Factor (BF) is the ratio between the power measured on the front side and the power measured on the rear side, both under STC conditions (i.e. 1000W/m² illumination etc.).

Influence: The bifacial gain is directly dependent on BF – if the BF was doubled while all other parameters stayed the same, then the bifacial gain would in principle also be doubled.

Rear Side Shading

Definition: Sum of everything obstructing light sources (sky, clouds, reflection from ground) for the rear side of the module.

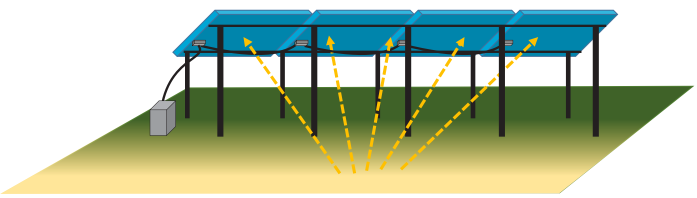

Figure 6: Every obstacle which obstructs the rear surface of the modules reduces the amount of irradiance which can contribute to the bifacial gain (e.g. mounting system, cables etc.).

Influence: Every obstacle which eclipses the rear surface of the modules reduces the amount of irradiance which can contribute to the bifacial gain (e.g. mounting system, cables etc.).

Note: Small shadows from frame, j-box and cables are not detrimental. The advantages of the frame (see chapter „Introduction“) outweigh the small effect on the module’s bifaciality factor. Shading elements like rails or purlins of mounting system behind the module rear side should be avoided.

Mounting Type: Fixed Tilt vs. Tracker Application

Definition: Fixed tilt systems are ground mounted PV installations with a constant angle between module plane and the ground, typically facing south. Tracker application (here: single axis tracker) refer to modules mounted on a mechanical system which adapts the module tilt angle for the respective changing sun position.

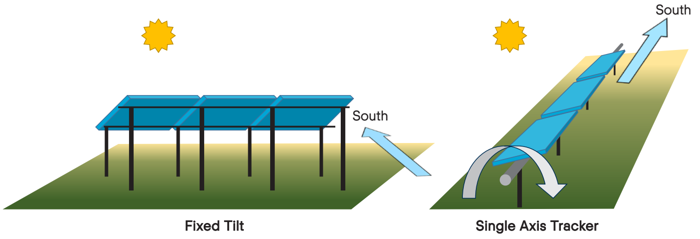

Figure 7: Fixed Tilt vs. Tracker application

Influence: Generally tracker systems provide a higher electrical yield than fixed tilt systems, but at the same time are more expensive in installation and operation. A tracker system targets to optimize the front side yield. However, the combination of tracker application with bifacial modules usually makes sense (for details see chapter „d. Discussion of Parameter Interactions“).

Row to Row Distance (“Pitch”)

The very commonly used term “Ground Coverage Ratio (GCR)” = area of modules in the system / total system area is proportional to 1/pitch.

Definition: Distance between two rows of modules in a fixed tilt or tracker system (see below figure).

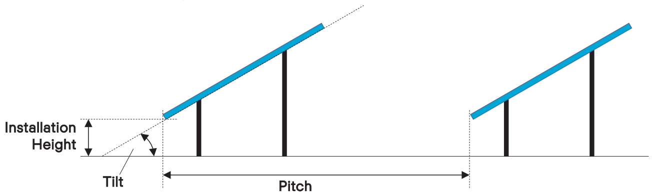

Figure 8: Fixed tilt systems: Row-to-row distance (pitch), module tilt and installation height. One row of modules can basically contain one or more modules in vertical – see „Module Configuration“.

Influence: Higher row to row distance leads to a higher bifacial gain because more illuminated ground is effective for the rear side of the module.

Module Tilt for Fixed Tilt Systems

Definition: Angle between module plane and ground (see fig. 8).

Influence: With higher angles the irradiance on the module’s rear side increases.

Note: Axis tilt for tracker bifacial systems is not considered here, because currently, single axis trackers with horizontal axis are the main type of tracker application.

Installation Height

Definition: Height of the lowest module edge in a row above the ground (see fig. 8).

Influence: The bifacial gain increases with increasing Installation Height but saturates at a certain, system dependent limit.

Module Configuration

Definition: Module configuration in this context shall refer to the combination of two parameters: 1. vertical number of modules in one row and 2. module orientation (landscape or portrait) – see fig. 9 and 10. For fixed tilt typical vertical numbers of module in a row are between two and five modules, for tracker applications it is usually one or two.

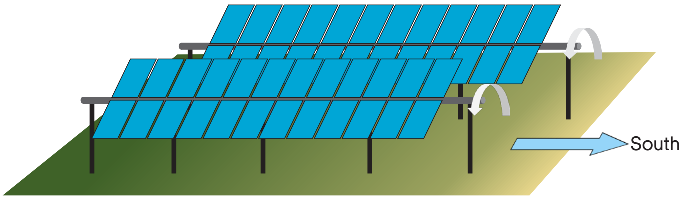

Figure 9: Example for module configuration in a tracker system: 2 modules per row, module orientation Portrait.

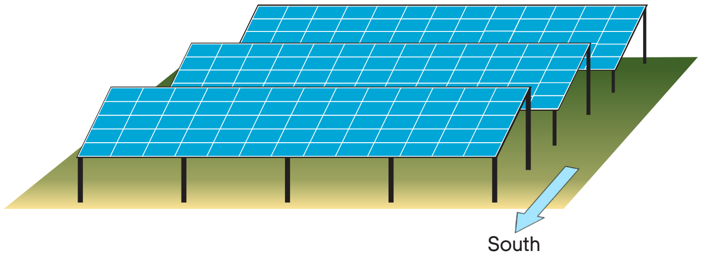

Figure 10: Example for module configuration in a fixed tilt system: 5 modules per row, module orientation landscape.

Influence: The vertical number of modules in each row influences the bifacial gain through the size of the row’s shadow on the ground. Nevertheless this effect can be compensated by adapting the row to row distance and the module installation height (see fig. 11).

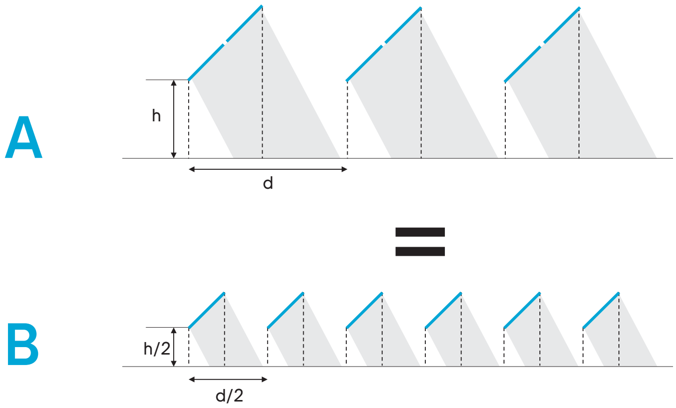

Figure 11: Equivalence of systems which are geometrically similar: the bifacial gain of a system with 2 modules per row is the same like for a (geometrically similar) system with 1 module per row and half pitch and installation height.

The two systems in figure 11 include the same number of modules, have the same GCR implemented and geometric similarity (including proportional module installation height). These two systems are equivalent with respect to bifacial gain. For both, fixed tilt or tracker, portrait or landscape module orientation is possible. The difference between portrait and landscape orientation on the bifacial gain is similar to the change of vertical number of modules per row as described above.

b. Location Parameters with Influence on Bifacial Gain

Ground Albedo

Definition: Albedo is defined as the amount of solar irradiance that is reflected as diffuse light by the ground.

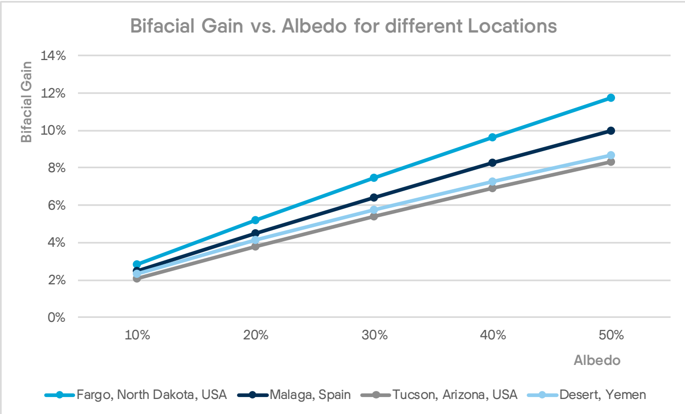

Figure 12: The Ground Albedo directly affects the Bifacial Gain but its effect depends also on the irradiance, i.e. on the geographic location.

Influence: With higher albedo value the bifacial gain increases. The correlation between bifacial gain and albedo is widely linear for a given system setup.

Typical albedo values for reasonable materials like bright sand, concrete or gravel are in the range between 20 % and 30 %. Significantly higher values (up to 80 %) are possible with snow, white paint or metal foils which all have limited lifetimes and therefore are only of temporary use. However, some days of snow can already have a measurable impact on the yearly energy yield.

Irradiance in total and especially the Share of Diffuse Irradiation

Definition: Irradiance refers to the amount solar radiation reaching the area of the PV system.

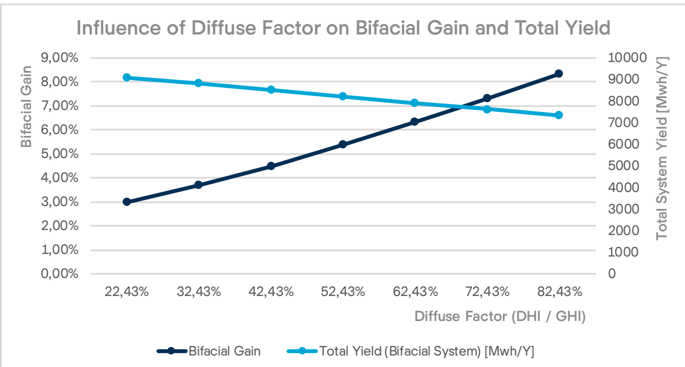

Figure 13: A higher share of diffusive light (Diffusive Horizontal Irradiance/Global Horizontal Irradiance) leads to a higher Bifacial Gain, but the total electricity yield of the system decreases at the same time.

Influence: For the bifacial gain the total irradiance has a small impact compared to the impact of other parameters like albedo. Decisive for the total yield is the total irradiance, but front side yield and rear side yield increase both, so the relative bifacial gain is not strongly affected. Much more influence on the bifacial gain comes with the respective irradiation angle over the time of day and the change of seasons and the respective share of diffuse irradiation. Generally a higher share of diffuse irradiation leads to less total yield but higher bifacial gain (see figure 13).

Note: Figure 13 is an example that higher bifacial gain not necessarily means a higher total energy (electricity) yield.

Precipitation

Definition: Amount and form of rain (snow, hail) on the area of the PV installation.

Influence: The precipitation influences the Bifa Gain because it changes the albedo of the ground (e.g. wet stones compared to dry stones) and generally influences the soiling (the front side is usually affected stronger than the rear side of the module).

Backtracking algorithm for Tracker Systems

Definition: For tracker systems there is usually a software used to control the minimum and maximum tilt angles reached by the modules in order to avoid shading of the following row of modules. There are multiple different approaches for these algorithms which are usually proprietary for each tracker brand. This gains importance for non-ideal ground shapes (i.e. not perfectly even).

Influence: Because the tracking and backtracking algorithm determines the actual module tilts, the bifacial gain is influenced through the mechanism described for the module tilt parameter (see above). The actual impact depends on the specific algorithm.

c. Interacting Effects of Design Parameters

This section intends to highlight interacting effects of system parameters with respect to bifacial gain or more precisely the optimization of the total energy yield. This means the effect of the change of a certain parameter (see section „a. Design Parameters with Influence on Bifacial Gain") might depend on the value of another parameter.

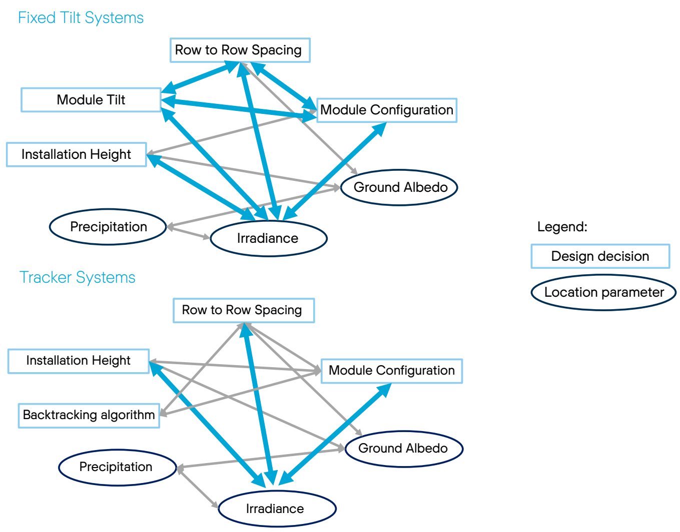

Figure 14: Schematic of parameter interactions.

Note: The interaction between module configuration and row to row spacing is related to the situation of geometric similarity, see section „a. Design Parameters with Influence on Bifacial Gain".

d. Discussion of Parameter Interactions

Tracker vs. Fixed Tilt with Bifacial

Tracker and bifacial work together, the bifacial gain will normally be even better for tracker systems than for fixed tilt systems, and this is why:
For the usage of tracker systems to make sense, certain conditions have to be met anyway: Tracker systems are usually used in areas with high irradiation and high sun positions at noon. Moreover usage of trackers is normally combined with high pitch. Since these two conditions are also ideal for bifacial modules, the bifacial gain for a tracker system will be better than for a fixed tilt system (which normally has a smaller row to row distance and lower irradiation)

Note: With identical system parameters (foremost the same installation height, same pitch, same location with the same irradiance), bifacial gain measured for a fixed tilt system would be higher than that of a tracker system, because the tracker system is targeting to improve the front side yield (and the bifacial gain is measured relatively to the front side yield). But basically it makes no sense to build tracker and fixed tilt systems with identical parameters.

For example a tracker system will have a higher pitch to avoid row to row shading than a fixed tilt system, because the maximum reached module tilt is higher. Lastly the exact numbers for bifacial gain depend on the detailed project parameters.

Tracker and Fixed Tilt - Interaction between Irradiance and Installation Height

More installation height will increase the bifacial gain (up to a certain saturation limit), but it will also cost money. Given that all other parameters remain constant, the irradiance will influence, how much more yield is gained with increasing height. In other words a change in irradiance (e.g. on a different location) can lead to a different optimum in installation height.

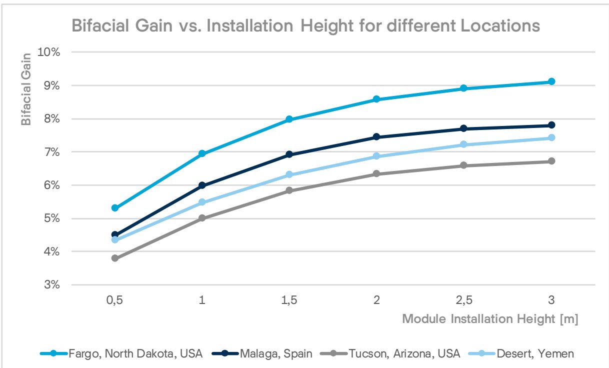

Figure 15: Bifacial gain vs. installation height for several geographic locations. Increasing installation height leads to more light on the ground behind the modules which can illuminate the module rear sides and therefore the bifacial gain. However, it also increases the system costs.

Tracker and Fixed Tilt - Interaction between Irradiance and Row to Row Spacing

More row to row spacing will increase the bifacial gain (up to a certain saturation limit), but it will also cost money. Given that all other parameters remain constant, the irradiance will influence, how much more yield is gained with increasing height. In other words, a change in irradiance (e.g. on a different location) can lead to a different optimum in row to row spacing.

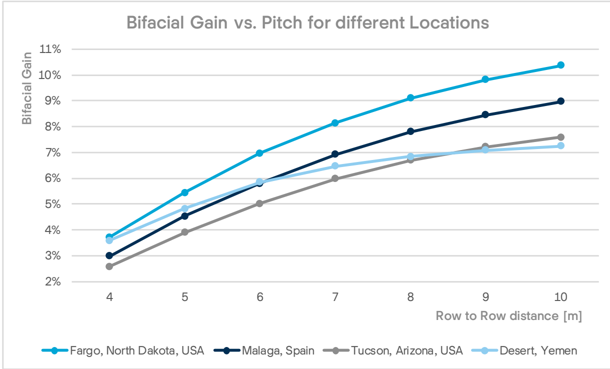

Figure 16: Bifacial gain vs. row-to-row distance for several geographic locations. Similar to increased installation heights increased pitches lead to more light onto the modules' rear sides. Again at the expense of higher installation costs - due to larger ground area for the same system size.

Note: The dependency graphs for irradiance vs. installation height and irradiance vs. row-to-row spacing look very similar. This is no coincidence, as explained with fig. 11.

Tracker and Fixed Tilt - Interaction between Irradiance and Module Configuration

The module configuration influences the shadowing on the ground. The effect of a changing module configuration on the bifacial gain could be compensated by changing the installation height, the row to row spacing or both. Thus the ideal module configuration is dependent on the irradiance through the dependence of those two parameters on the irradiance.

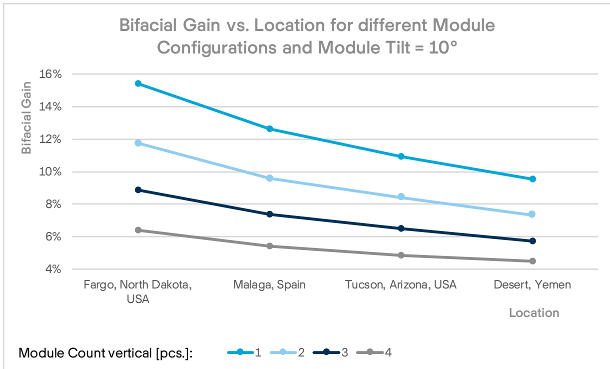

Figure 17: Bifacial gain vs. location for different module configurations (vertical numbers of modules per row): More modules per row (at the same pitch) mean less light on the ground behind the modules and therefore less bifacial gain.

Note: In order to get the same bifacial gain with a higher number of modules per row the pitch and/or installation height must be increased accordingly (see fig. 11).

Fixed Tilt only - Interaction between Module Tilt and Irradiance

At fixed row-to-row distance and installation height a change in the tilt changes the amount of illuminated ground and therefore the irradiance to the modules' rear sides. The exact shadows and their quantitative effect to the bifacial gain depend on the irradiance over time: at one hand the angle of direct irradiance (position of the sun) and on the according share of diffusive light.

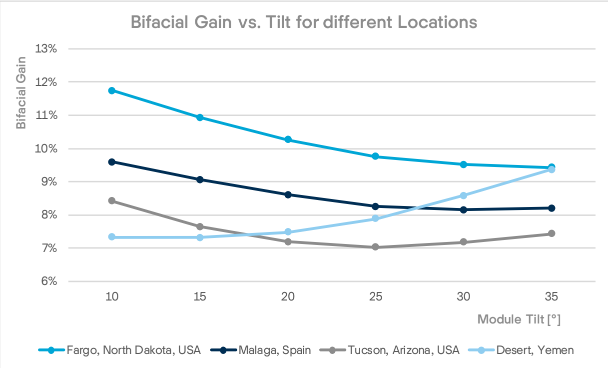

Figure 18: Bifacial gain vs. module tilt for different geographic locations.

Note: Yemen is another example for the front side yield dominating and the bifacial gain increasing because of front side yield reduction: whereas the bifacial gain is constantly increasing with the tilt, the total yield has its maximum at about 20° and decreases again for higher tilts.

Fixed Tilt only - Interaction between Module Tilt and Row-to-Row Spacing

Both parameters have an effect on the amount of illuminated ground (at a certain irradiance) and therefore on the amount of irradiance to the modules' rear sides. This depends sensitively on the location including its irradiance over the year. Therefore there is no general rule.

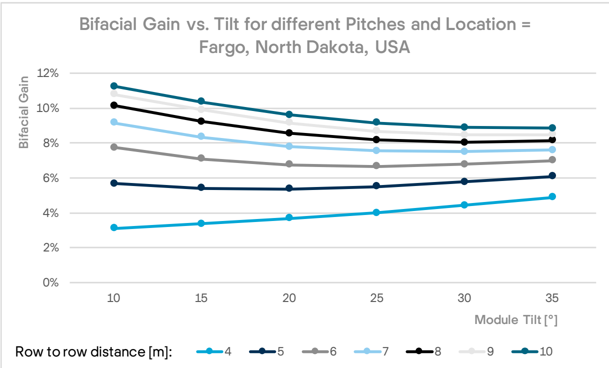

Figure 19: Bifacial gain vs. module tilt for different pitches at Fargo.

Fixed Tilt only - Interaction between Module Tilt and Module Configurations

Comparably to module tilt and pitch these two parameters determine the amount of directly illuminated ground at a certain irradiance and therefore have a direct effect on the irradiance to the modules' rear sides. This again sensitively depends on the location and therefore must be evaluated and optimized by an according simulation.

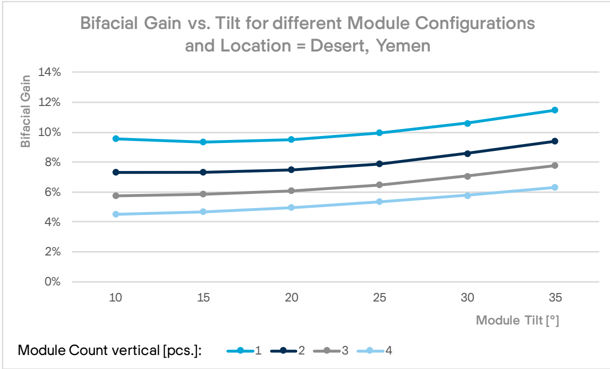

Figure 20: Bifacial gain vs. module tilt for several module configurations (number of modules per row) at Yemen. There is no general correlation, individual locations have to be simulated.

CONCLUSION

With bifacial modules, significantly higher electricity yields are possible than with standard monofacial modules. However, it is important to take some time for planning in order to gain optimal yields from the final PV installation. There are many more parameters and dependencies in a bifacial system which have to be considered. The most important of these parameters and dependencies have been described above. Whereas some of the above can basically put into a simple rule ("Get more light behind the modules!") the system optimization for a certain location considering additional costs in order to fulfil this rule requires more planning than for a standard monofacial system.

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